

Attachment H  
SWIFT Advanced Water Treatment  
Pilot Data Review

# Pilot Testing Review – April 2017



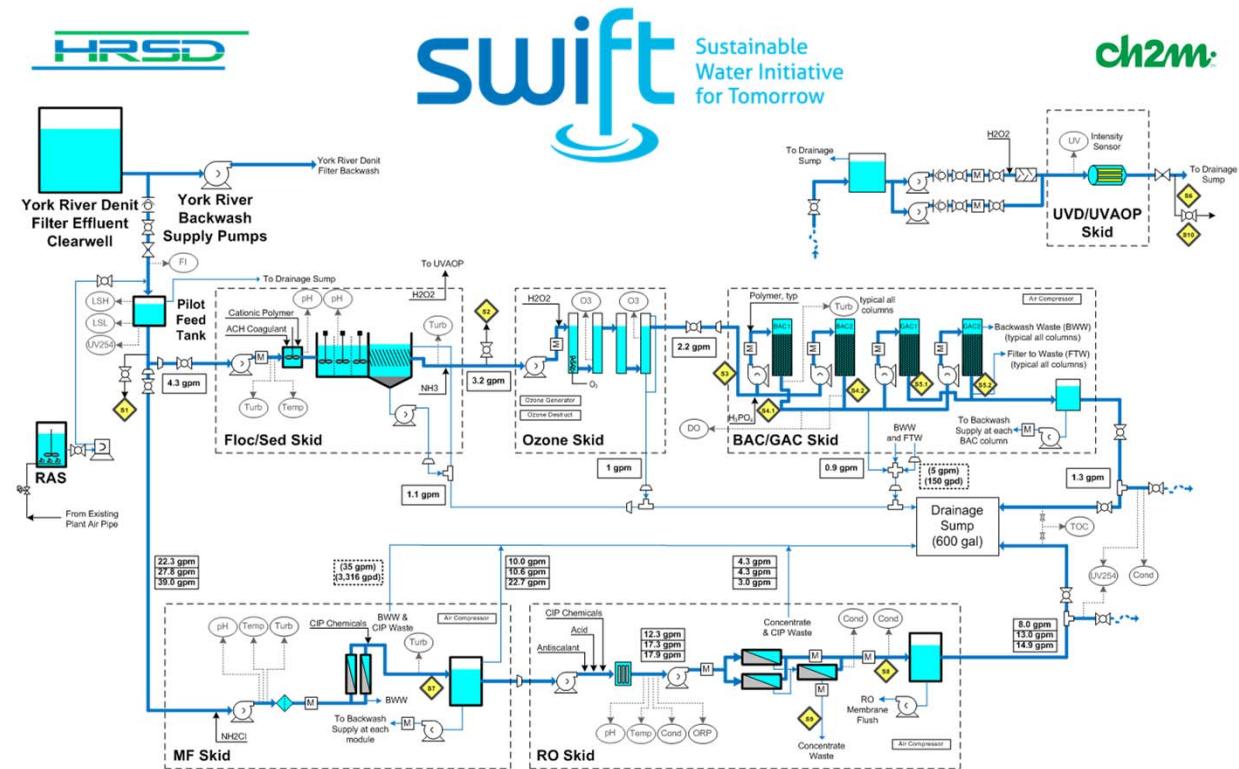


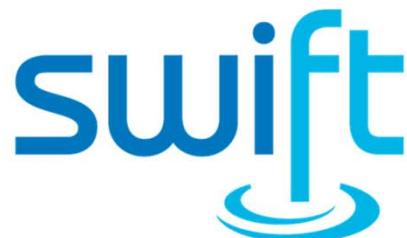
## Objectives

- Provide a detailed review of the pilot treatment performance
- Provide the baseline data to support SWIFT decisions

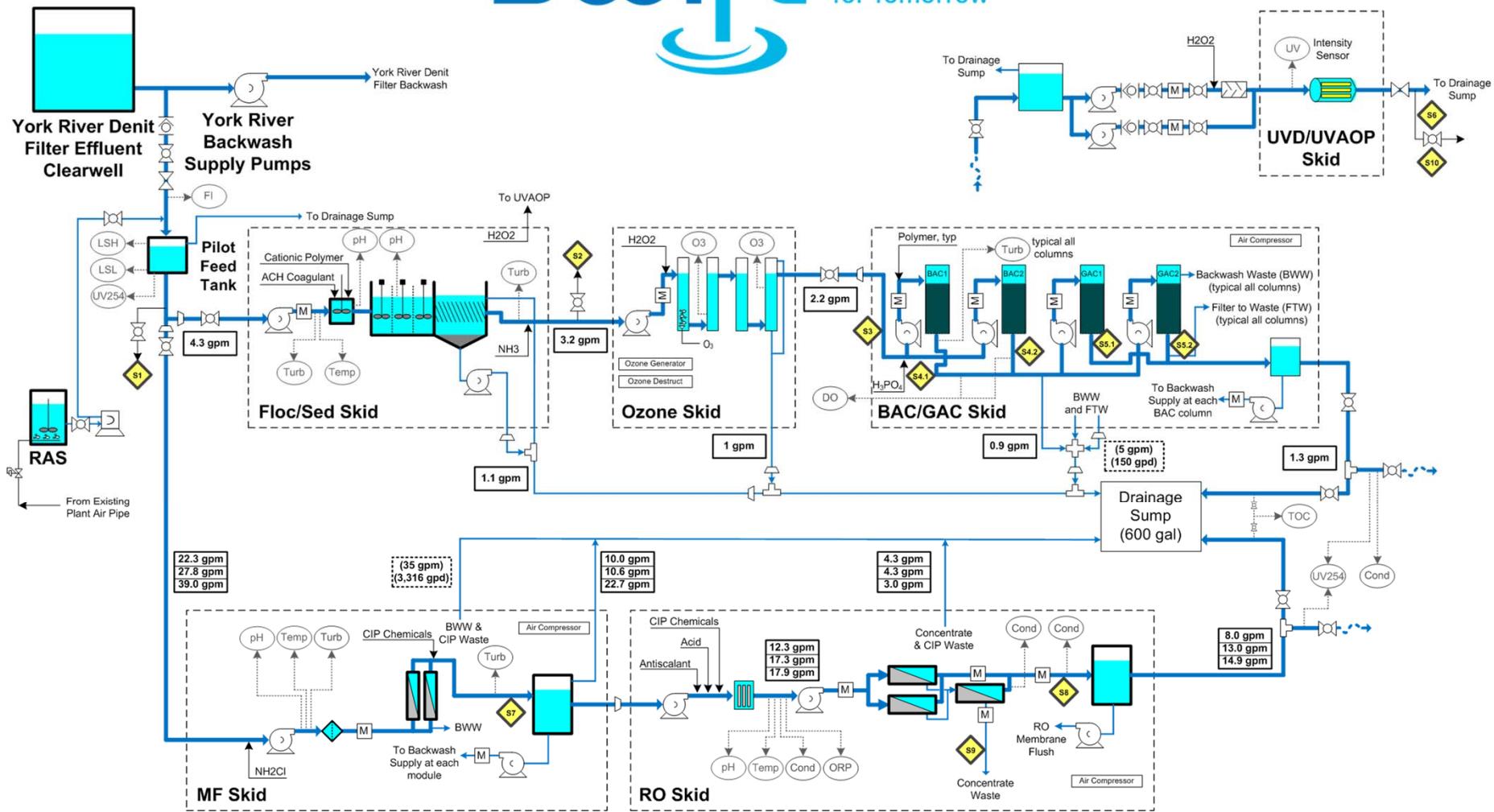
# PFD and Sample Location Review

- S1: Pilot Feed
- S2: Floc/Sed Effluent
- S3: Ozone Effluent
- S4.1: BAC1 Effluent
- S4.2: BAC2 Effluent
- S5.1: GAC1 Effluent
- S5.2: GAC2 Effluent
- S5.3: GAC Combined Effluent
- S6: UVD Effluent
- S7.1: Toray UF Effluent
- S7.2: Dow UF Effluent
- S7.3: Combined UF Effluent
- S8: RO Effluent
- S9: RO Concentrate
- S10: UVAOP Effluent





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## Pilot Testing Schedule

- June 2016: UF and RO skid commissioning
- July 2016: Floc/Sed, Ozone, BAC/GAC skid commissioning
- September 2016: Start of steady state operation
- December 2016: End of UF and RO skid operation
- June 2017?: End of Floc/Sed, Ozone, BAC/GAC testing period

# *Operational Review*



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## Operational Review Outline

- Ultrafiltration (UF)
- Reverse Osmosis (RO)
- Ultraviolet Advanced Oxidation Process (UVAOP) and Ultraviolet Disinfection (UVD)
- Rapid Mix, Flocculation, and Sedimentation (Floc/Sed)
- Ozone Oxidation
- Biologically Active Carbon (BAC) Filtration and Granular Activated Carbon (GAC) Adsorption

## Ultrafiltration

- Ultrafiltration equipment skid provided by Wigen and includes a DOW and a TORAY membrane module
- Monochloramine is fed upstream to reduce membrane fouling
- Ultrafiltration provides excellent turbidity removal and a barrier for pathogens (*Cryptosporidium* and *Giardia*)
- Design criteria:
  - Flux: 30 gallons per square foot per day (gfd)
  - Flow: 33 gpm
  - Max TMP: 25-30 psi

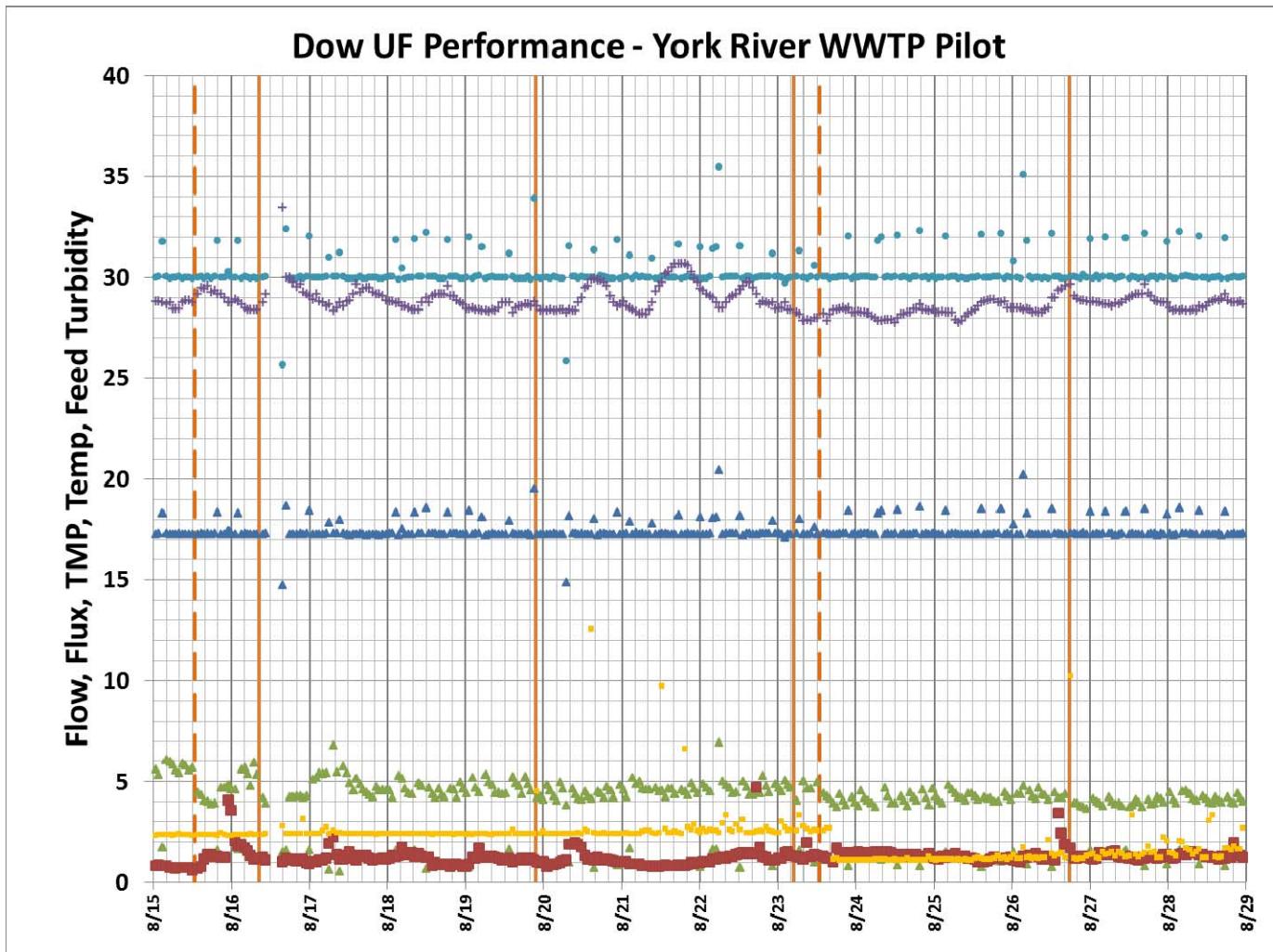


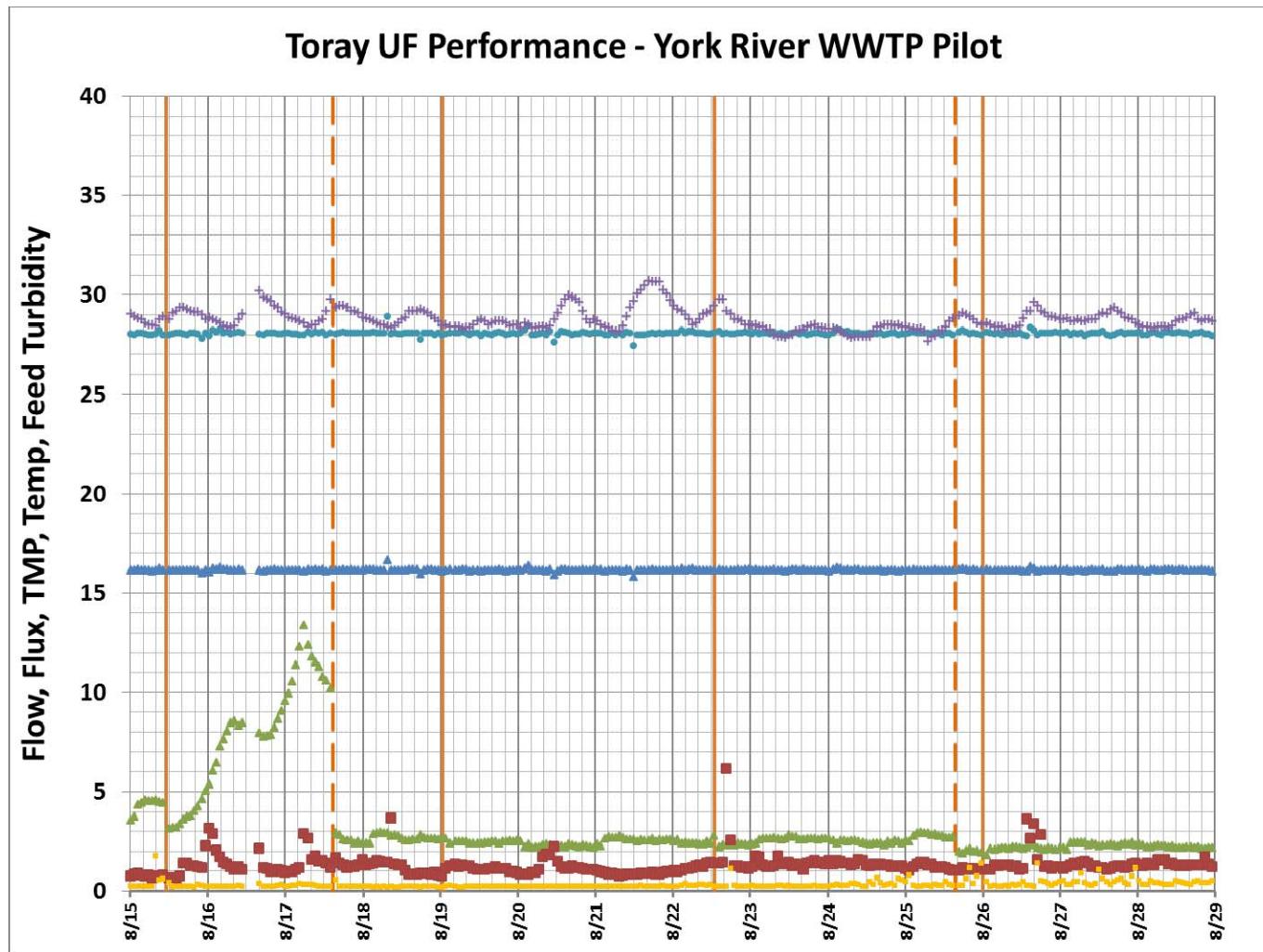
### UF skid operating protocol:

- Hourly backflushes
- Daily Integrity Tests (DITs)
- Mini-CIPs every 3 and 7 days
- Full CIPs in June, October, December

# Ultrafiltration

## Overall performance

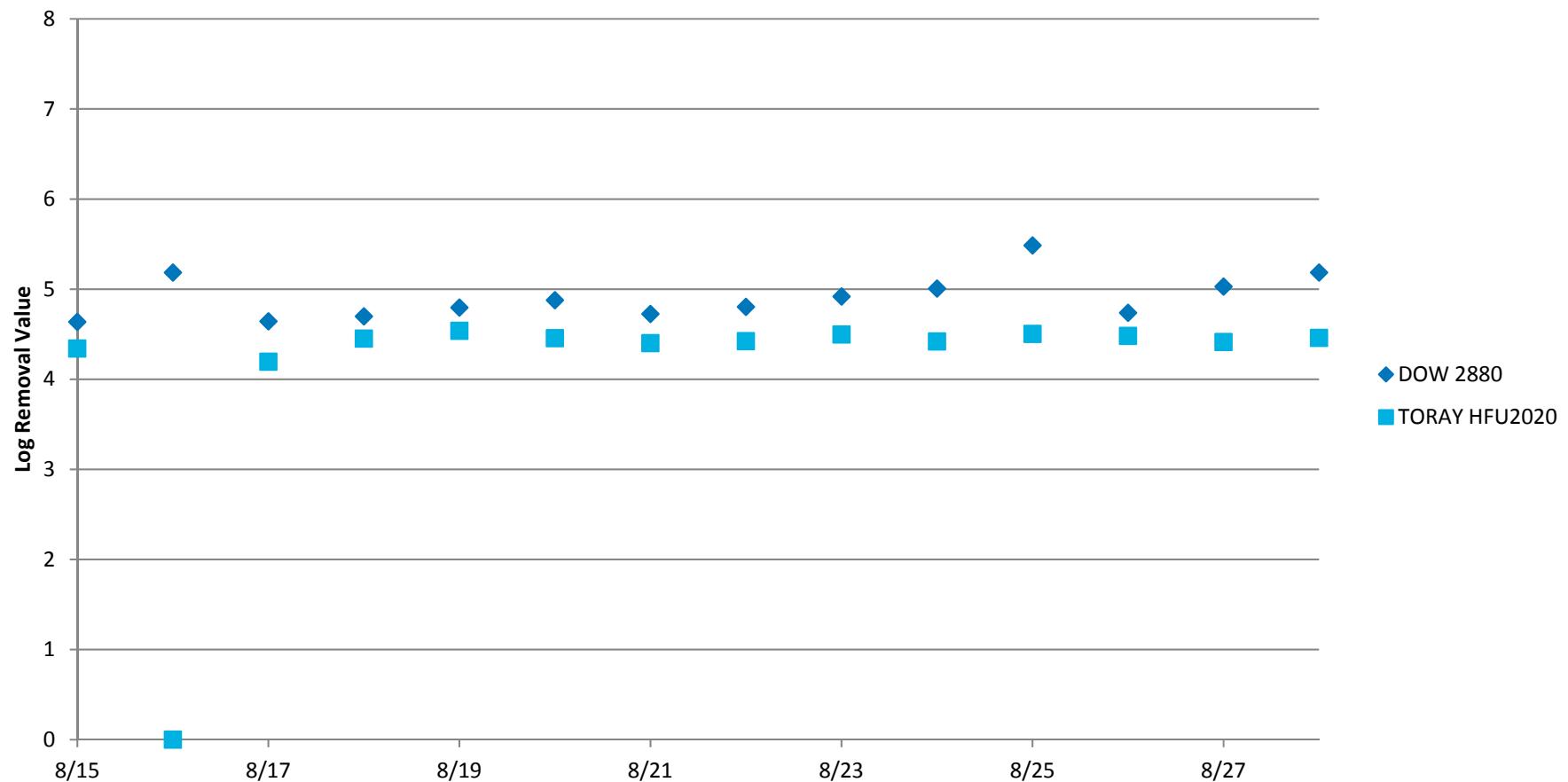




- Flux (gfd)
- ▲ Flow[gpm]
- + Temperature [C]
- ▲ TMP [psi]
- Feed Turbidity [NTU]
- ◇ Filtrate Turbidity/10 [mNTU]
- Alkaline Mini CIP
- Acid Mini CIP
- Full CIP

## Direct Integrity Tests (daily)

UF Membrane Log Removal Values





## Ultrafiltration Summary

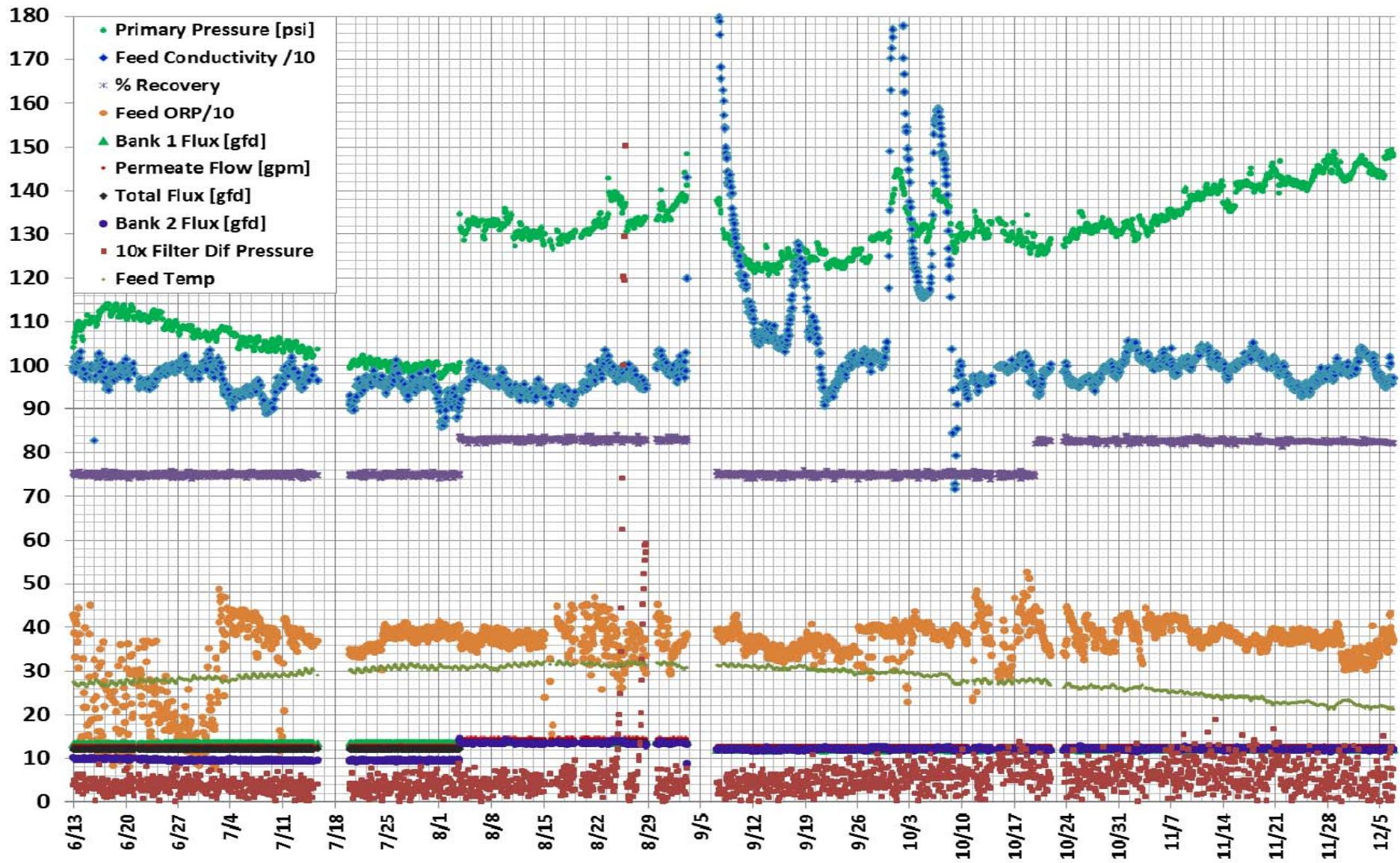
- Performance summary
  - Excellent performance of both membranes during DITs
  - Excellent effluent turbidity of both membranes
  - Excellent performance during MS2 virus challenge test (discussed later)
  
- Dow and Toray comparison
  - Both membranes achieved the design intent well
  - Toray membrane achieved a consistently lower TMP throughout pilot
  - Dow membrane proved more sensitive to pilot changes than the Toray membrane
  - Dow membrane experienced consistent effluent Total Coliform (discussed later)

## Reverse Osmosis

- RO skid provided by Wigen and includes Hydranautics elements
- RO provides an excellent barrier for pathogens and organics and also provides TDS removal
- Design criteria:
  - Permeate Flow: 12.8 gpm
  - Feed Flow: 15.4 gpm
  - Recovery: 83%
  - Flux: 12 gfd
  - Feed Pressure: 130 psi
  - RO array: 2:1

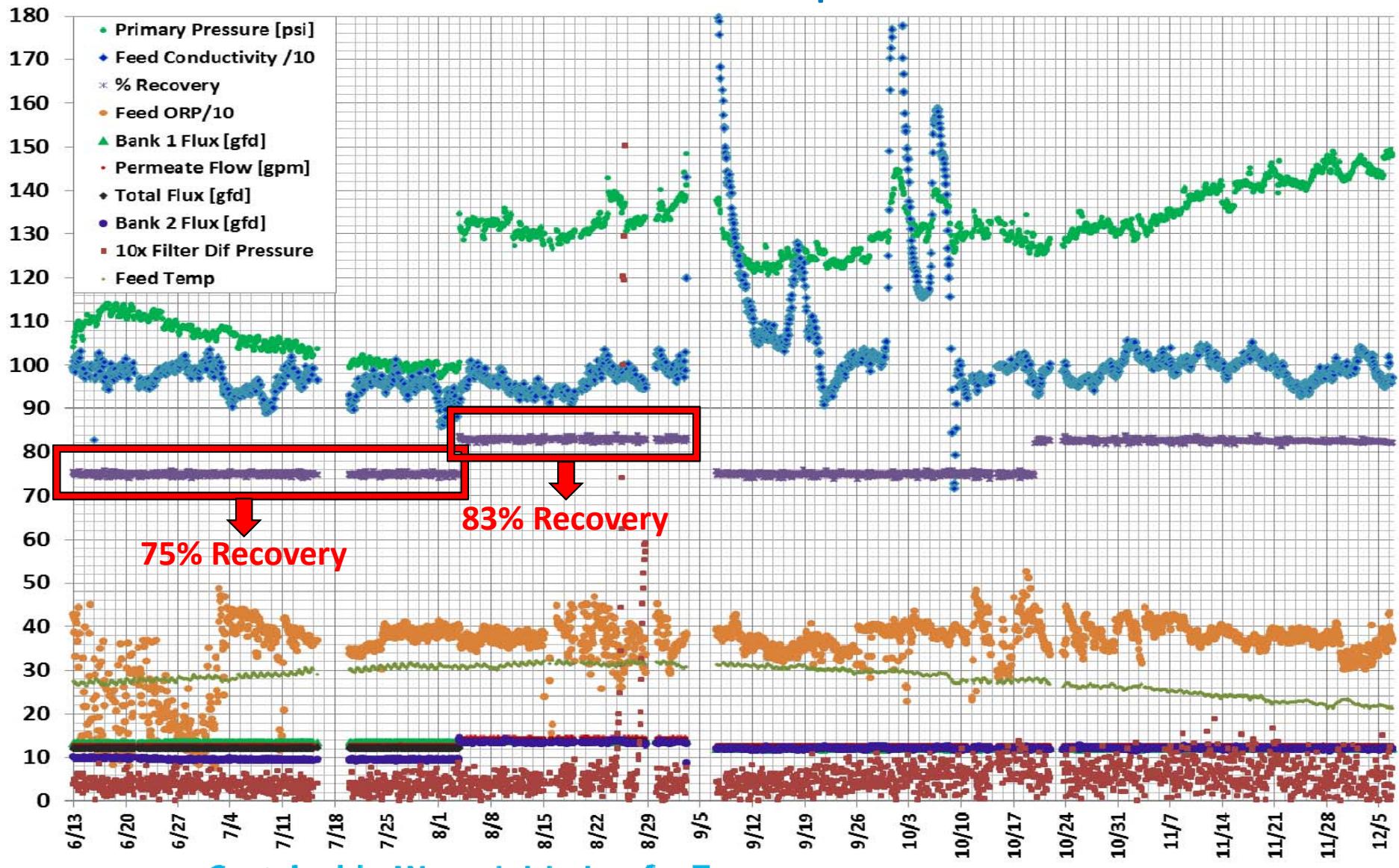


## Reverse Osmosis – Overall Performance



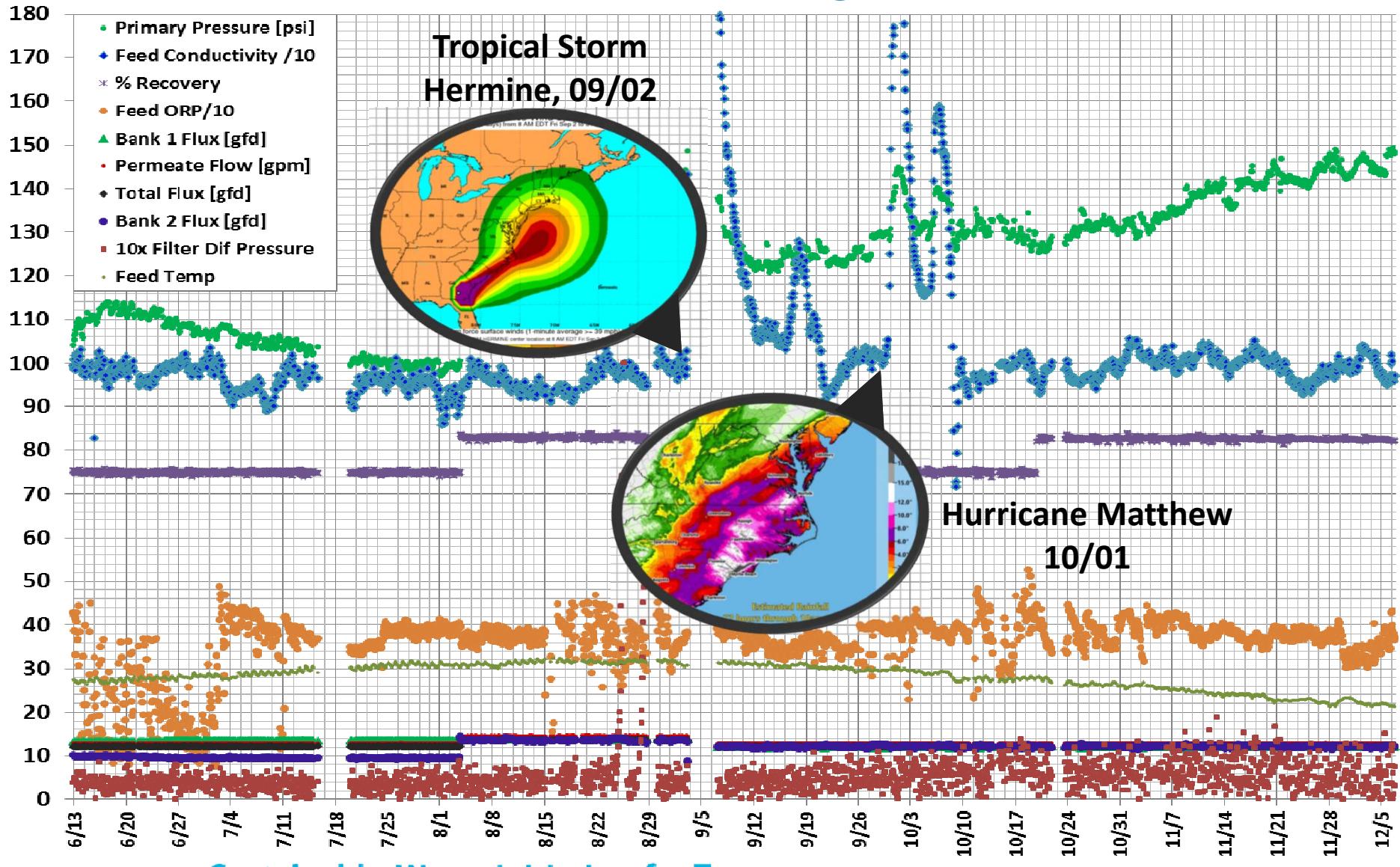
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## Reverse Osmosis – Operational Phases

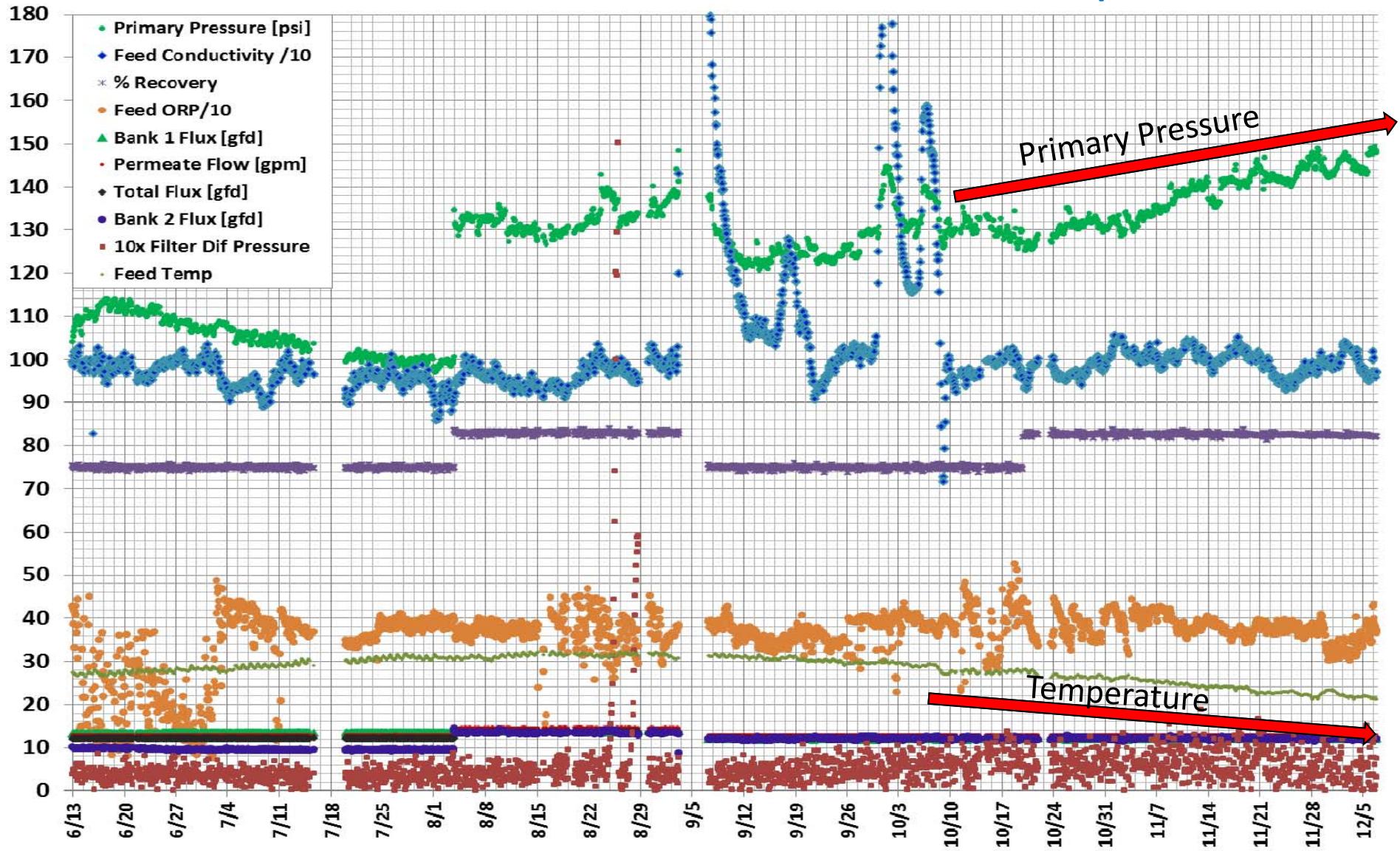


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## Reverse Osmosis – High Tide Events



## Reverse Osmosis – Pressure/Temperature



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## UVD and UVAOP

- UV lamp provided by Trojan
- Treats flows up to 30 gpm
- HRSD team installed skid:
  - Pump for UVD operation
  - Pump for UVAOP operation
  - Flow measurement for both pumps
  - Throttling valve for each pump
  - H<sub>2</sub>O<sub>2</sub> feed system
- Operating conditions:
  - RO effluent for UVAOP treatment always online
  - GAC effluent is directed to a UVD Feed Tank
  - Once per day, UVAOP is stopped and lamp is operated in UVD mode with GAC Effluent



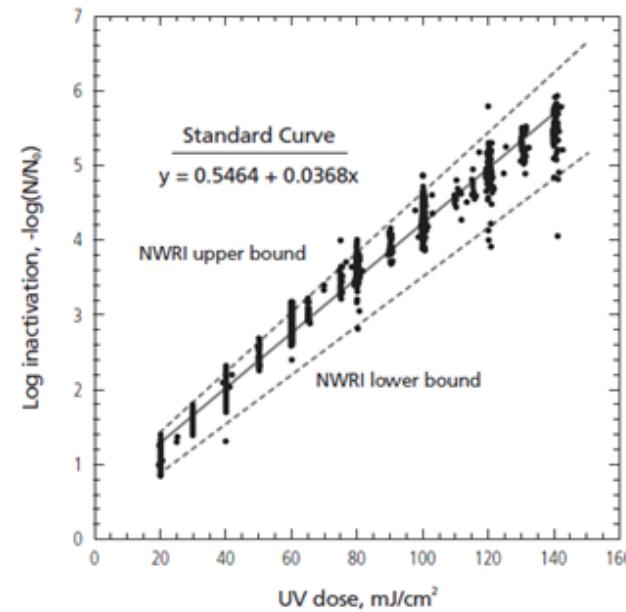
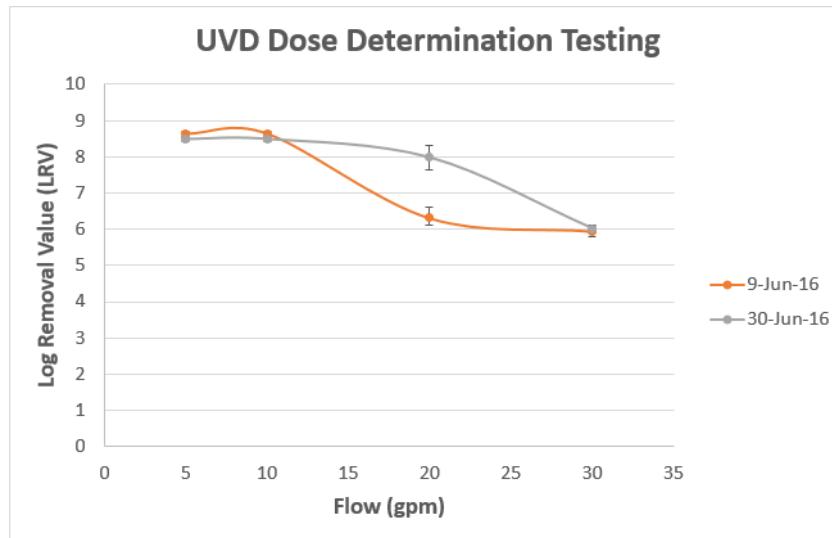


## UVD and UVAOP Dose Determination Testing

- UV dose is difficult to scale up from pilot to full-scale
- Approach: determine flow rate based on treatment performance against indicator contaminants
  - MS2 phage for UVD
  - 1,4-Dioxane for UVAOP

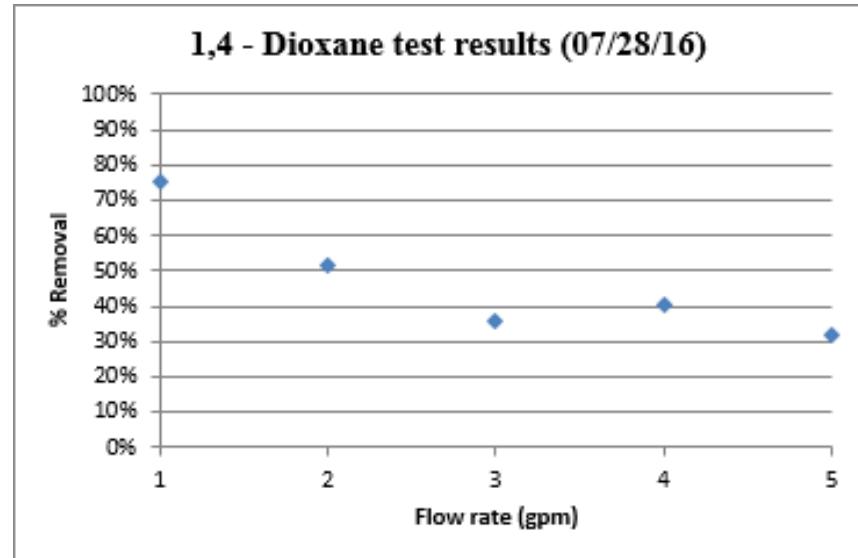
## UVD Dose Determination Testing

- 6-8 log removal of MS2 phage demonstrated for UVD flow rates from 5 to 30 gpm
- NWRI 2012 UV Guidelines correlate 6 log MS2 removal with a dose of 140 mJ/cm<sup>2</sup>



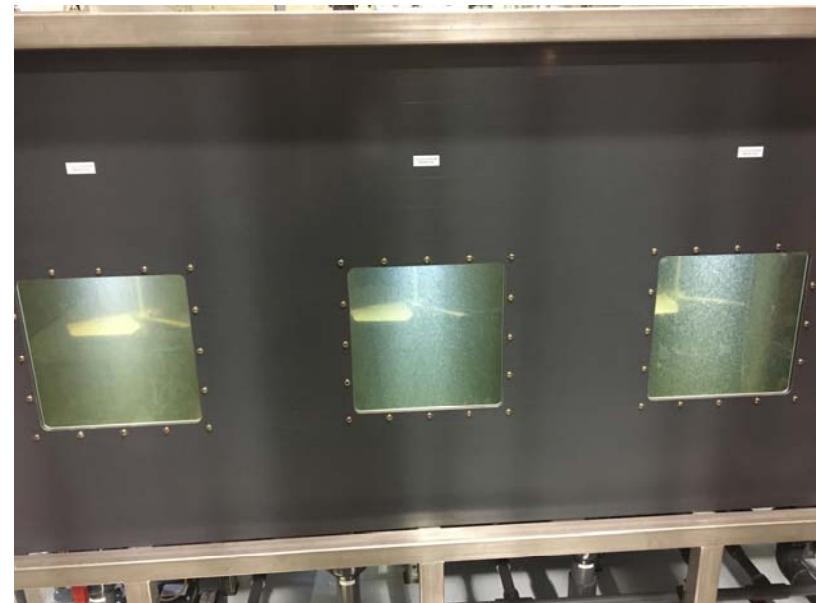
## UVAOP Dose Determination Testing

- Design target: 0.5 log removal of 1,4-Dioxane
- H<sub>2</sub>O<sub>2</sub> dose: 5 mg/L
- 0.5 log removal (~70% removal) achieved at 1-1.5 gpm

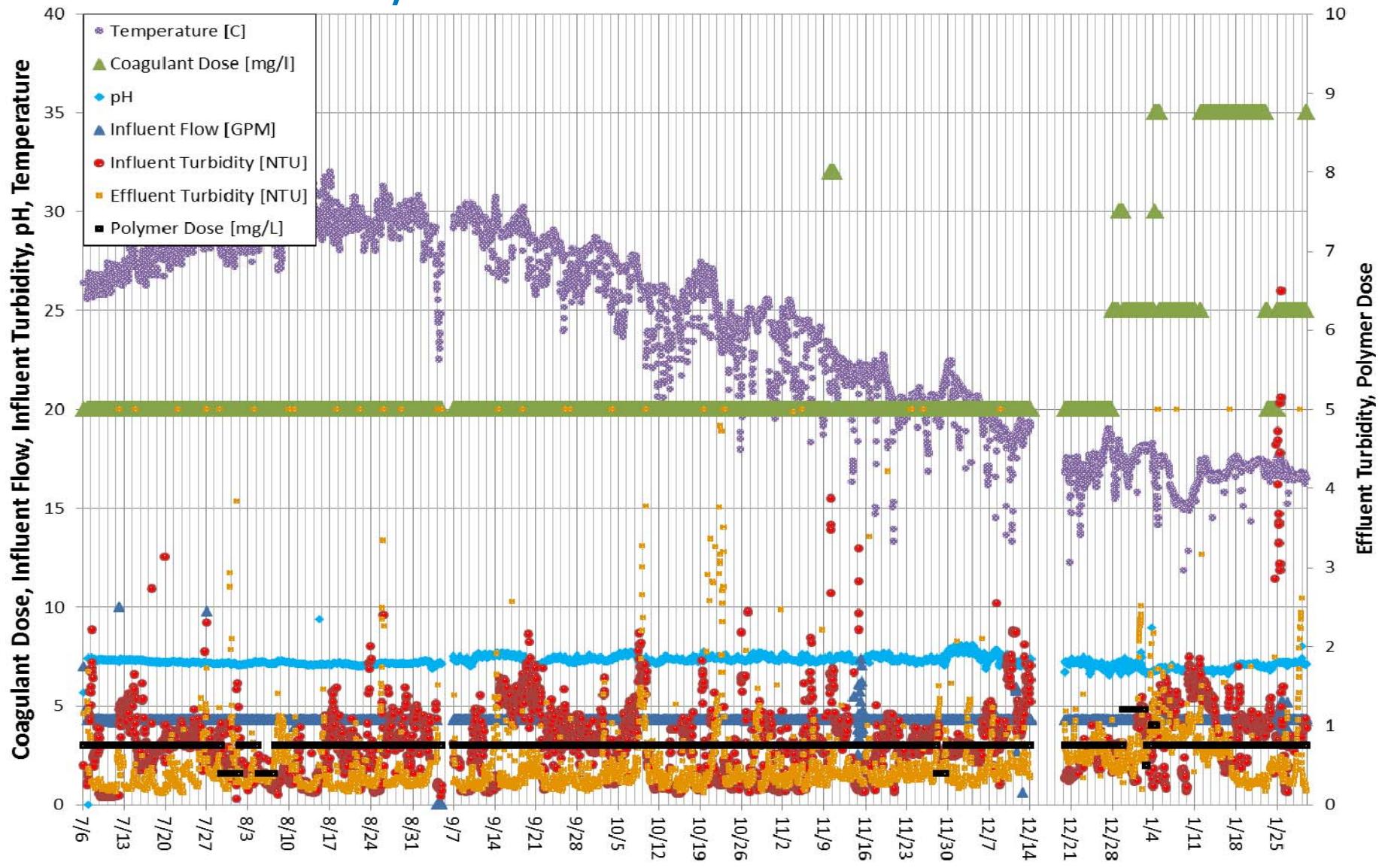


## Floc/Sed

- Floc/Sed skid provided by Intuitech
- Provides turbidity removal upstream of filtration
- Design criteria:
  - Flow: 4.4 gpm
  - 3-stage flocculation (18 min each)
  - Lamella plate loading rate: 0.1 gpm/sf
  - Coagulant: 20 mg/L ACH
  - Polymer: 0.75 mg/L cationic polymer

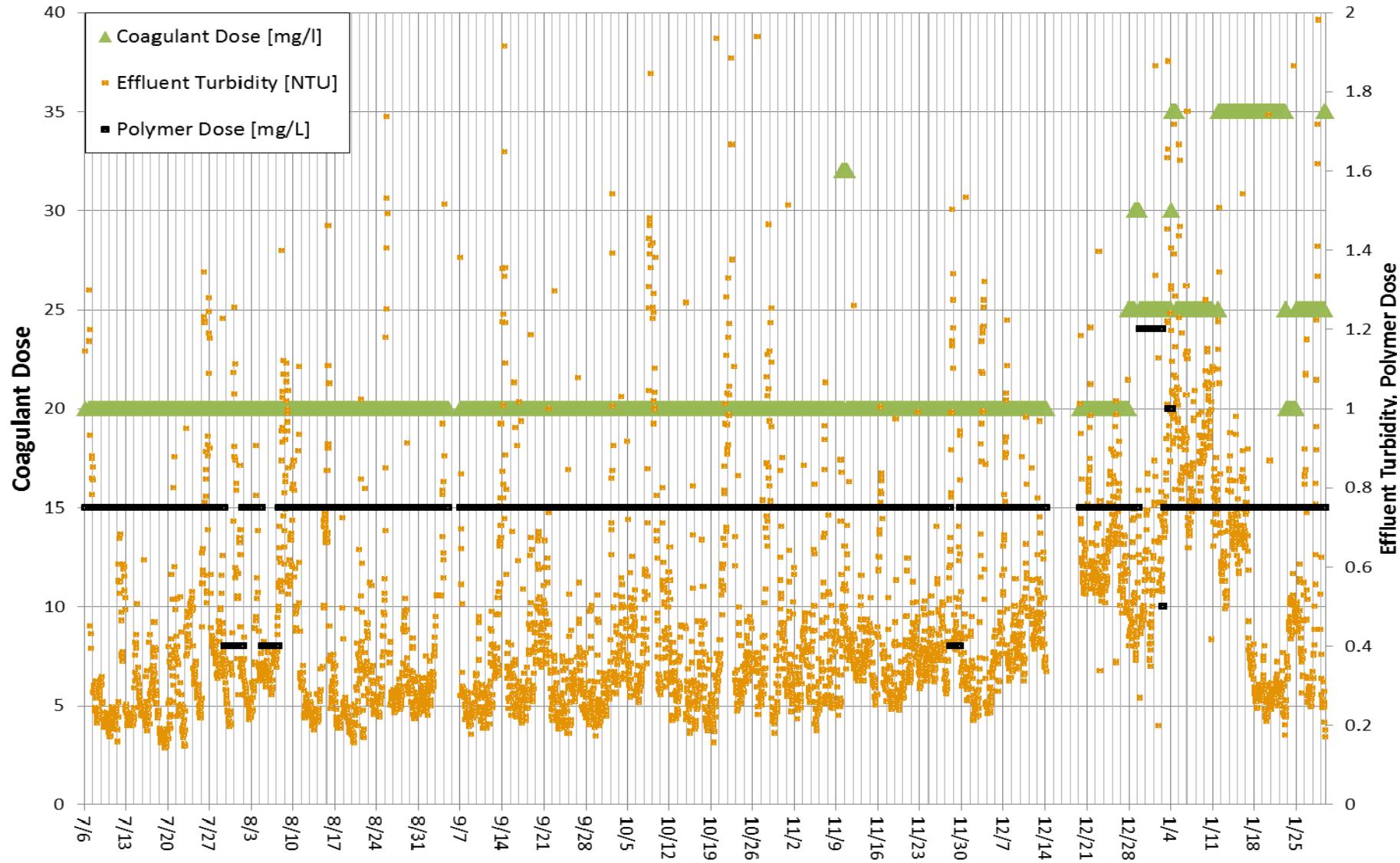


## Floc/Sed – Overall Performance



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## Floc/Sed – Effluent Turbidity



## Ozonation Introduction

- Provided by Intuitech, includes one dissolution chamber (glass) and four contact chambers
- Uses effluent from Flocculation & Sedimentation system, feeds BAC filtration
- Designed to operate at 3.2gpm, with varying doses of gaseous ozone and chemical ammendments



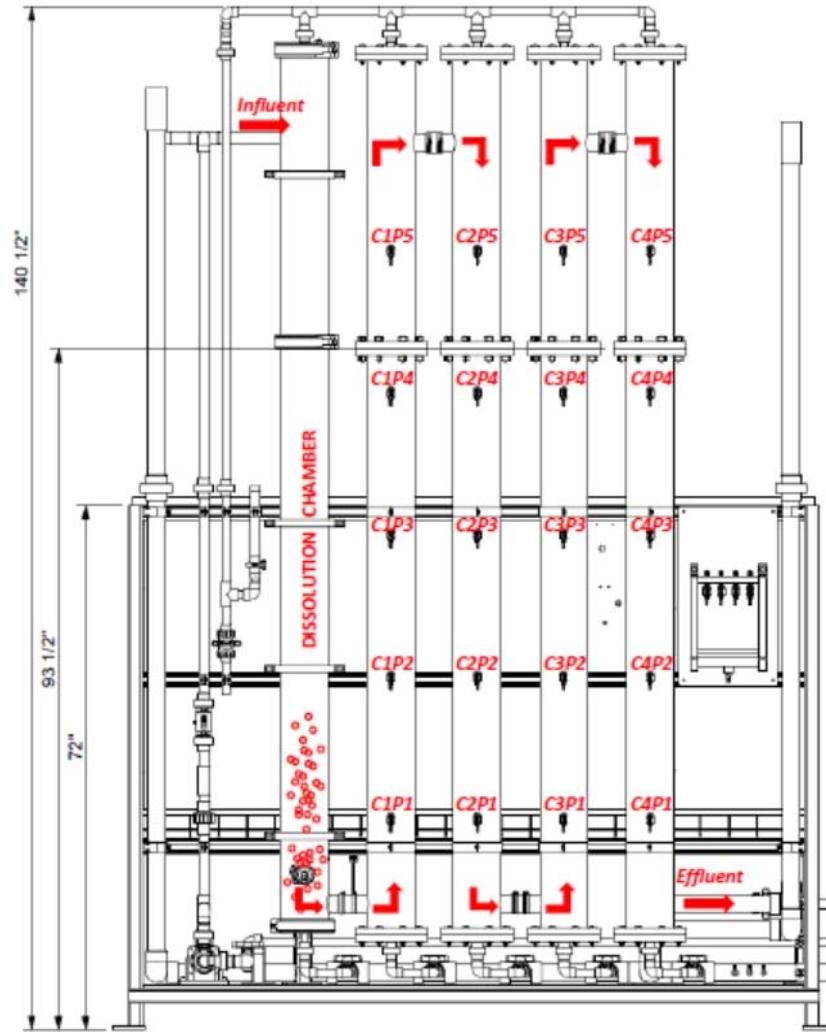
## Ozonation

- Main Purposes:

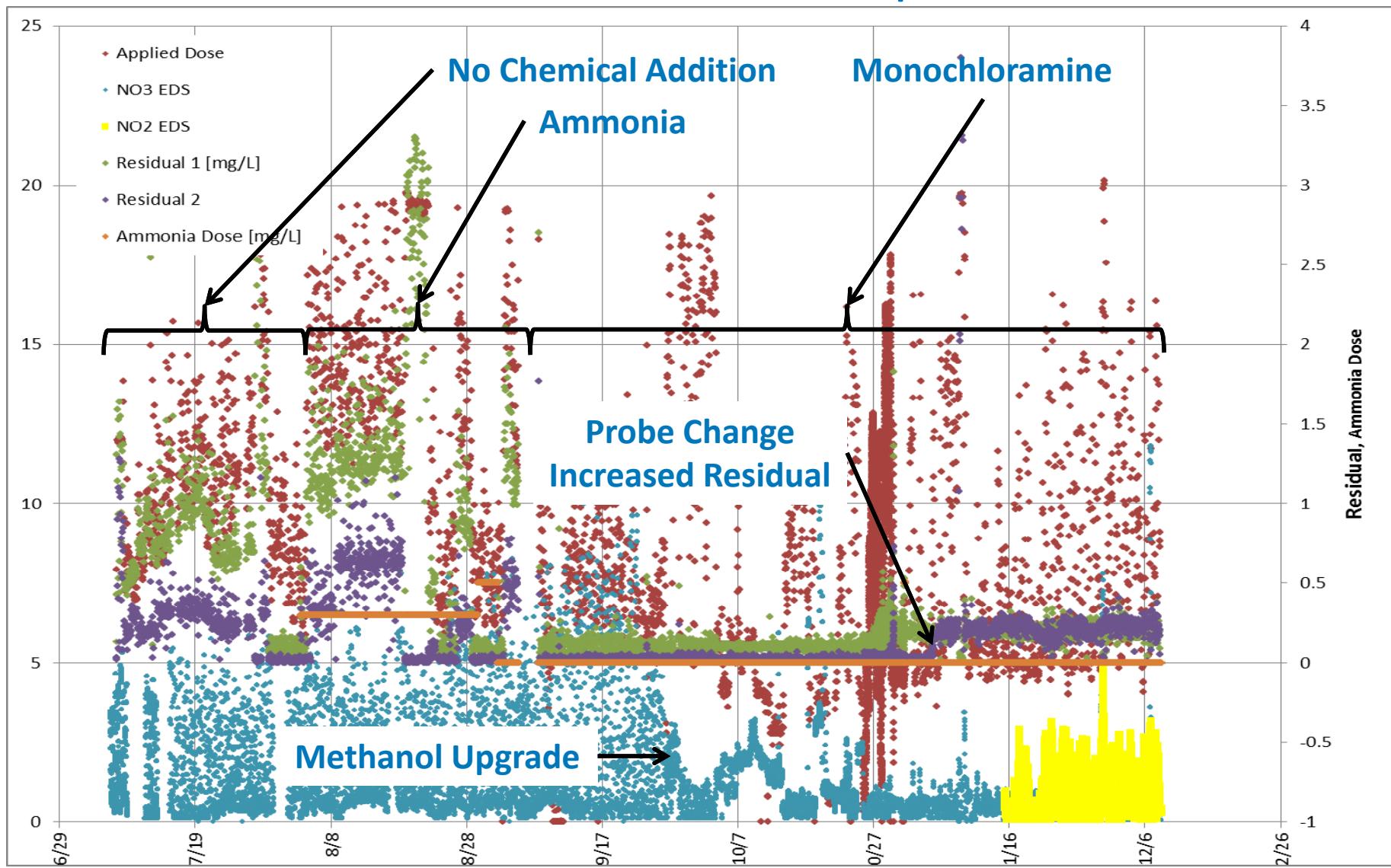
- Oxidize Recalcitrant organics (AOP): Pharmaceuticals and Personal Care Products (PPCPs), Contaminants of Emerging Concern (CECs)
- Increase biodegradability of organics in downstream BAC filters
- Pathogen inactivation
- Metals oxidation and precipitation
- Color, Taste, and Odor Removal

- Samples:

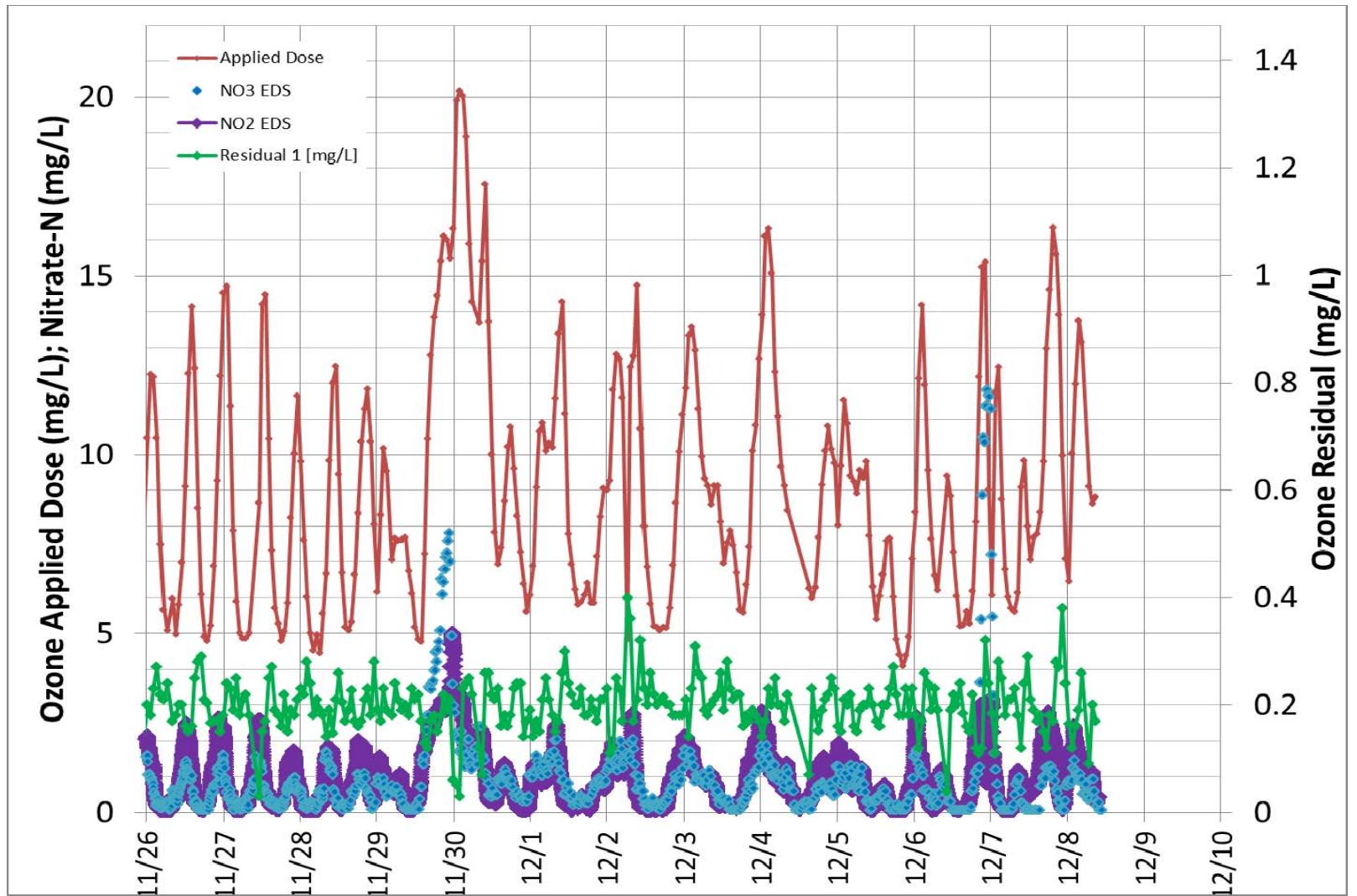
- Influent, Effluent, Column 1 Port 3



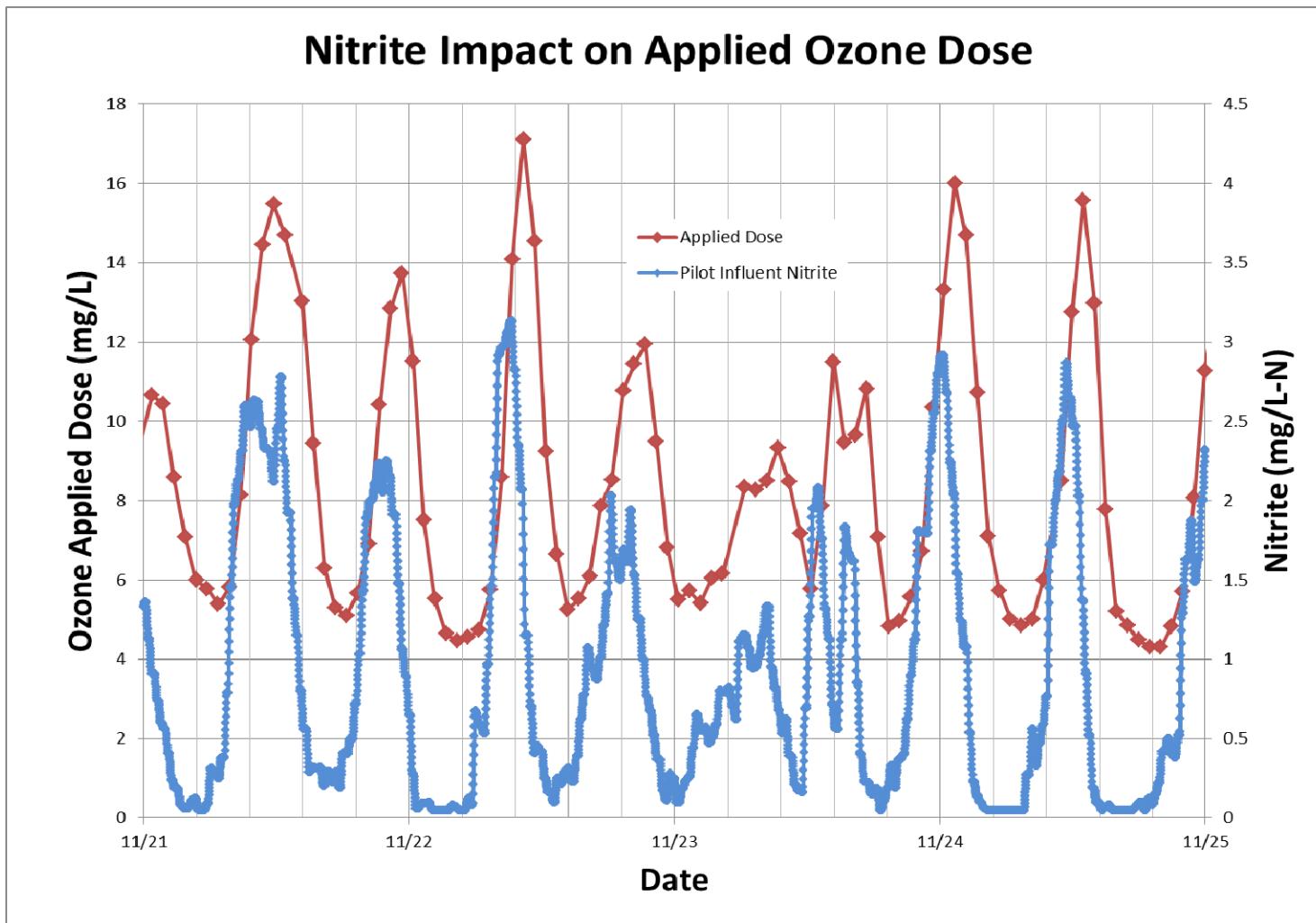
## Ozone Performance and Operational Phases



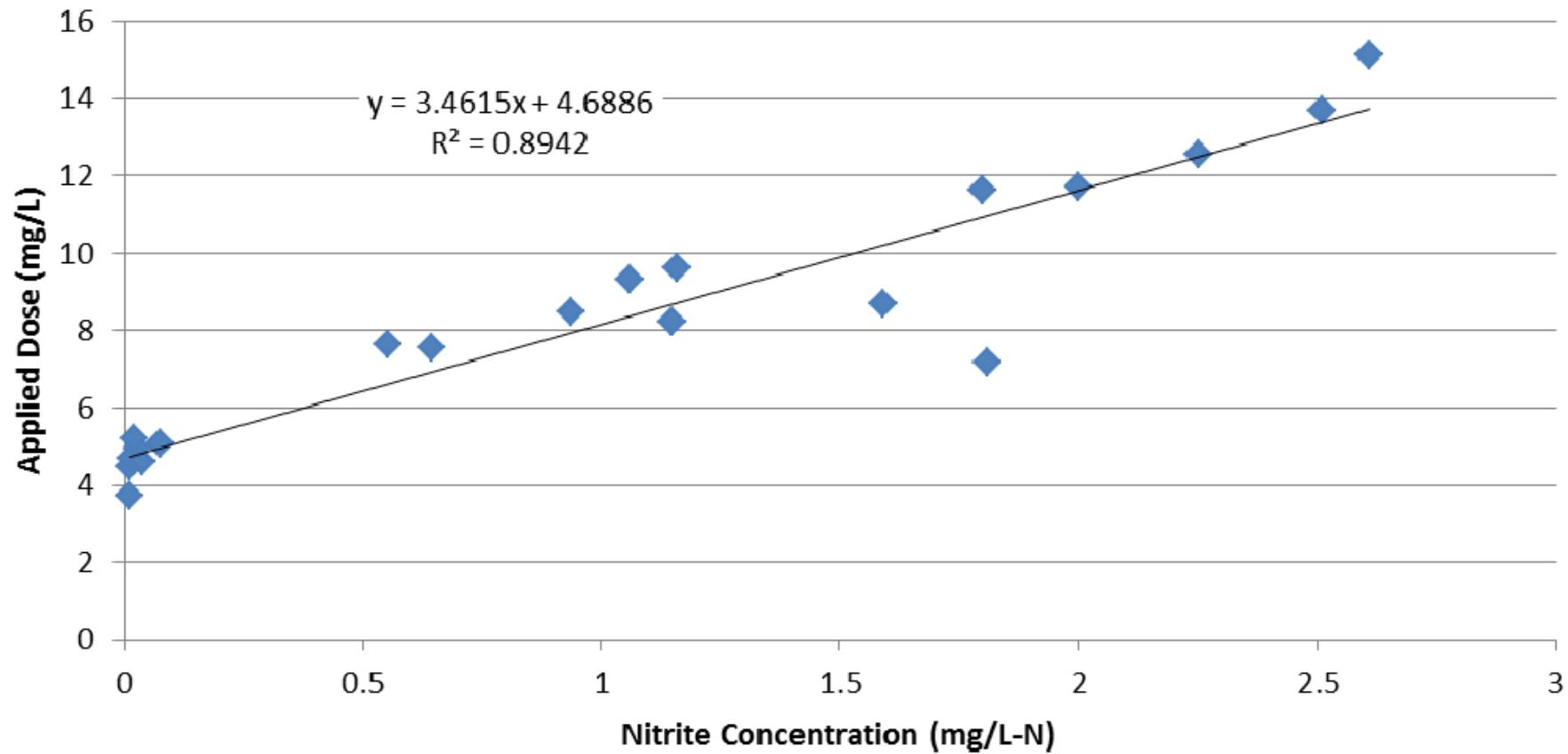
## Ozone Performance (Recent Data)



## Nitrite, applied dose and nitrate vs. time

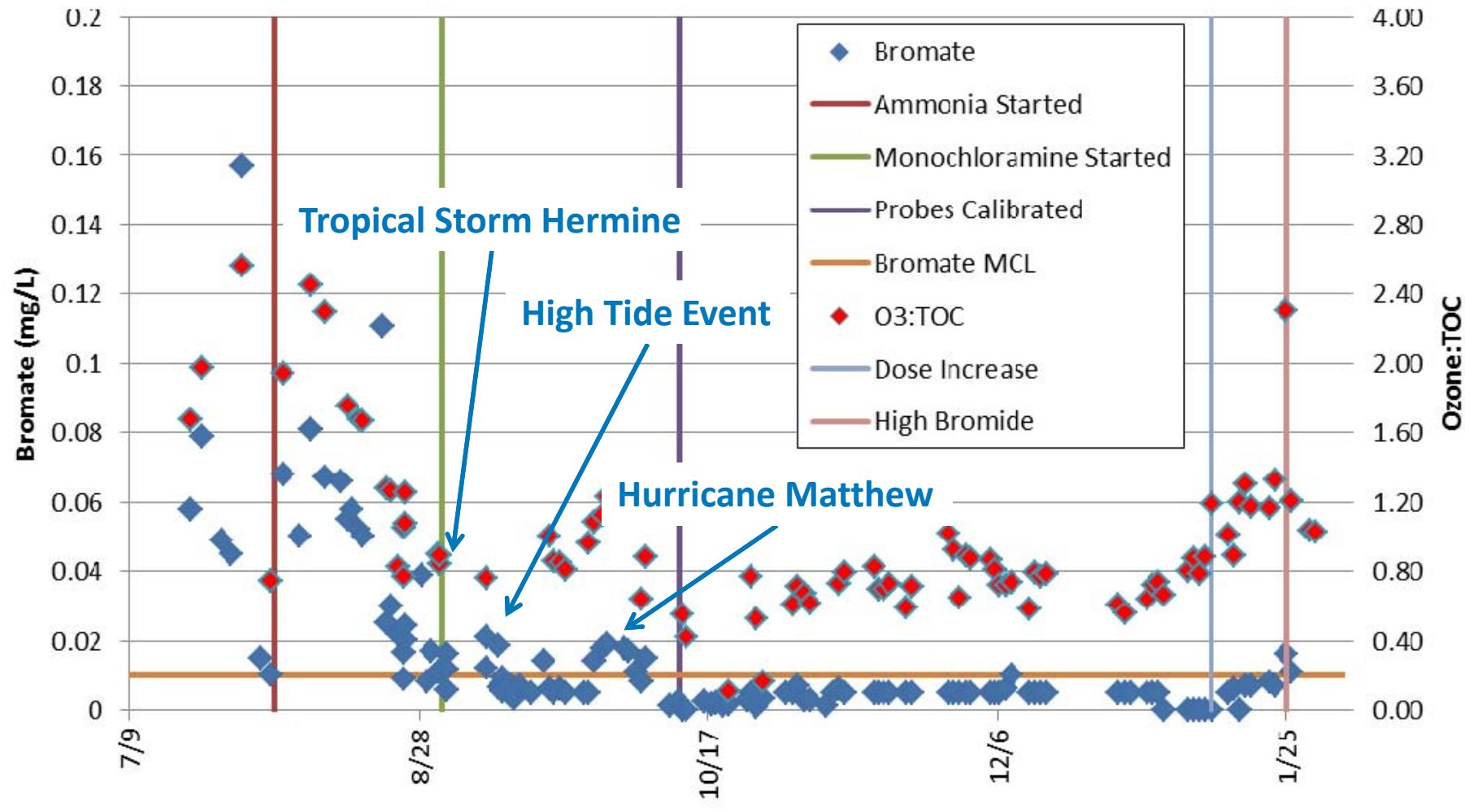


## Applied Dose vs Nitrite

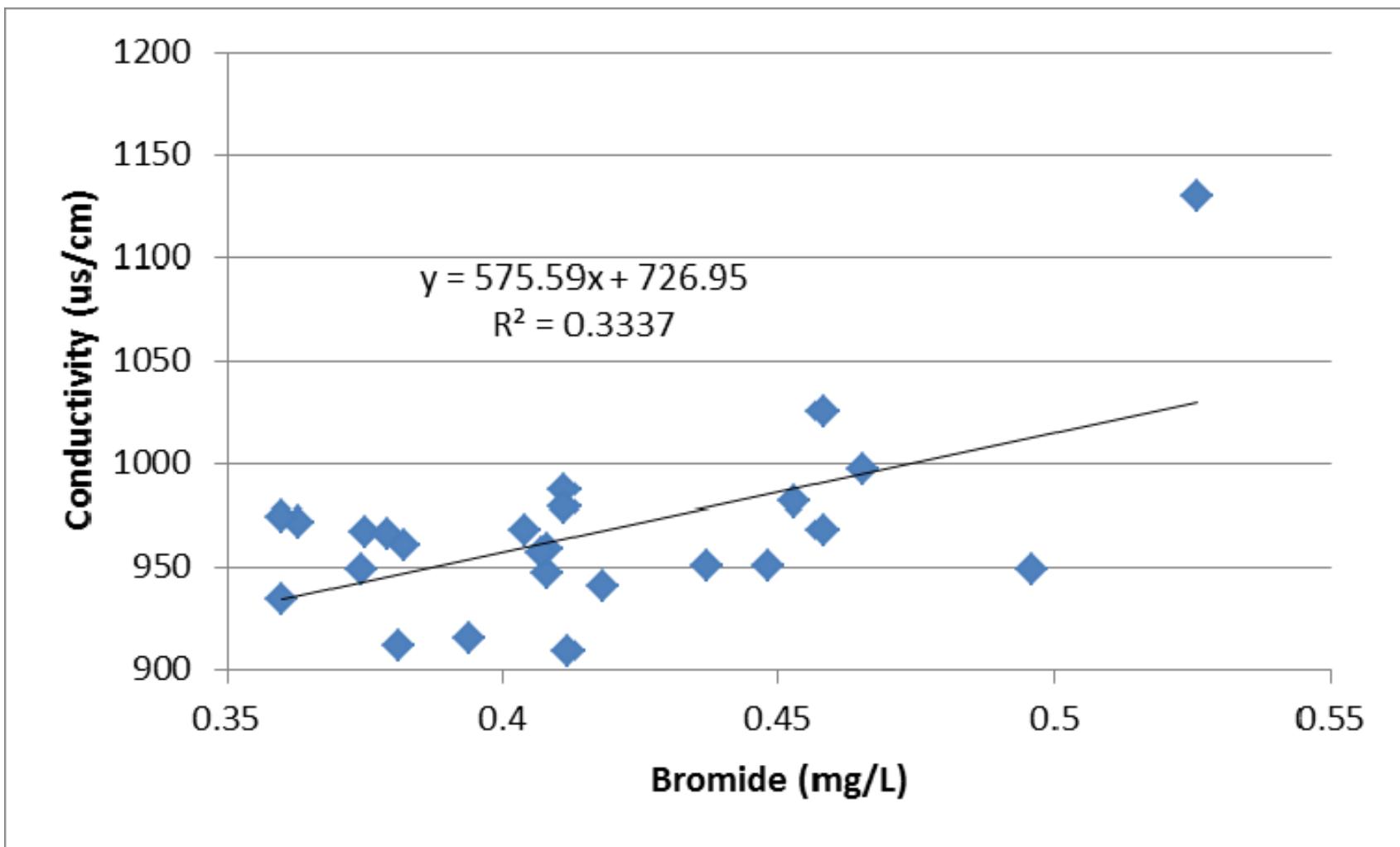


Stoichiometry = 3.43 g O<sub>3</sub>/g NO<sub>2</sub>-N

## Bromate Formation during Pilot Operation



## Bromide Concentrations





## BAC and GAC

### Introduction

- BAC/GAC skid provided by Intuitech.
- Design Criteria

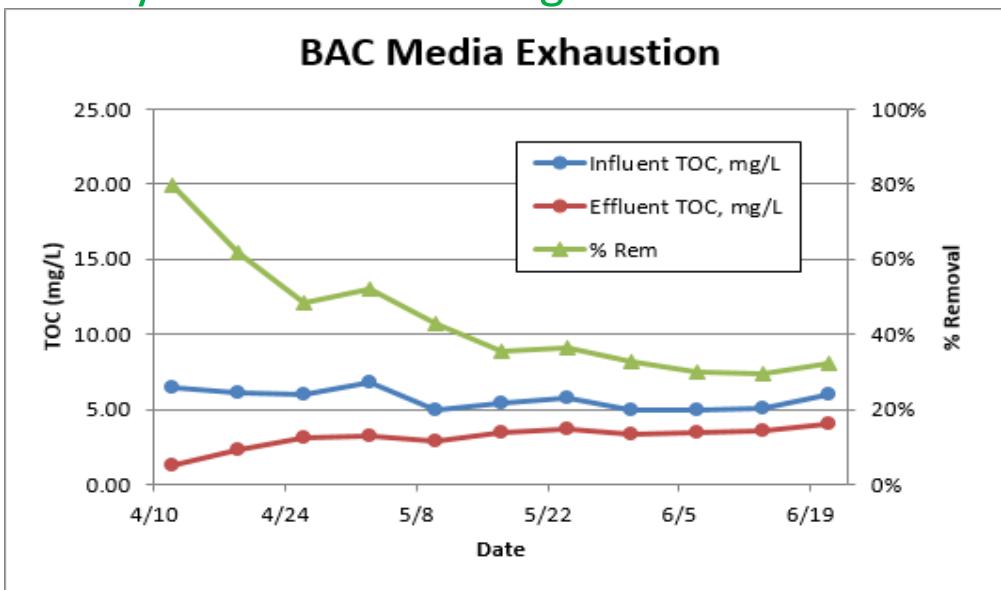
	Media Depth (ft)	EBCT (min)	Loading Rate (gpm/sf)	Flow Rate (gpm)
BAC High	5	5	7.5	1.47
BAC Low	5	10	3.7	0.73
GAC High	6	10	4.5	0.88
GAC Low	6	20	2.6	0.50

- BAC media (Calgon F816) supported by 12 inches of sand to enhance filtration
- GAC media (Calgon F400M) provides adsorption



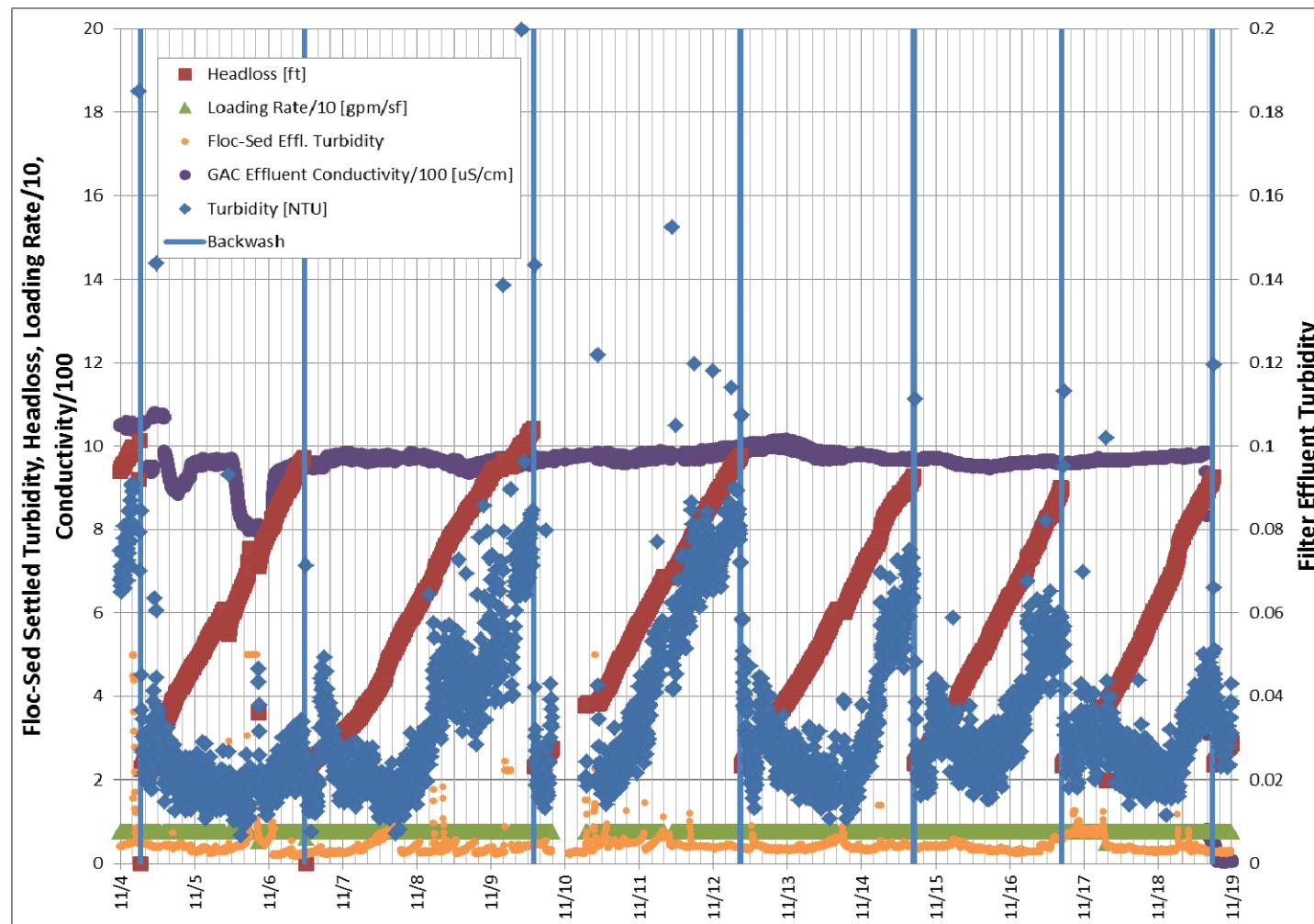
## BAC Media Exhaustion

- Prior to pilot, attempted to exhaust BAC media of adsorption properties
- Loaded media on Apr 7 at King William TP in test column
  - King William = 4-stage MBR + UV
- Initial 80% TOC removal
- Reduced to ~30% removal
- Media was loaded to pilot in July for commissioning



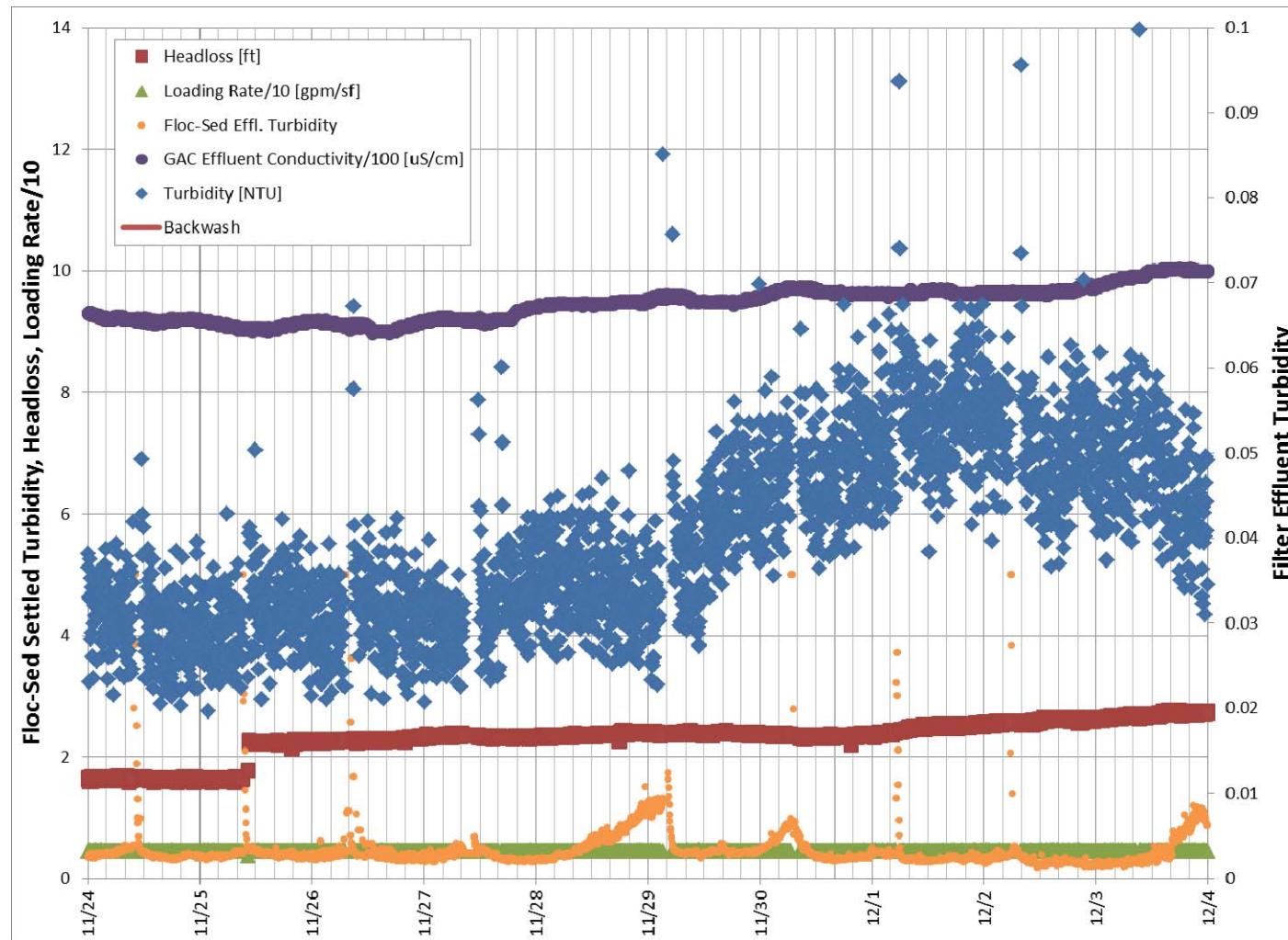
## BAC and GAC Overall performance

**BAC High**



## BAC and GAC Overall performance

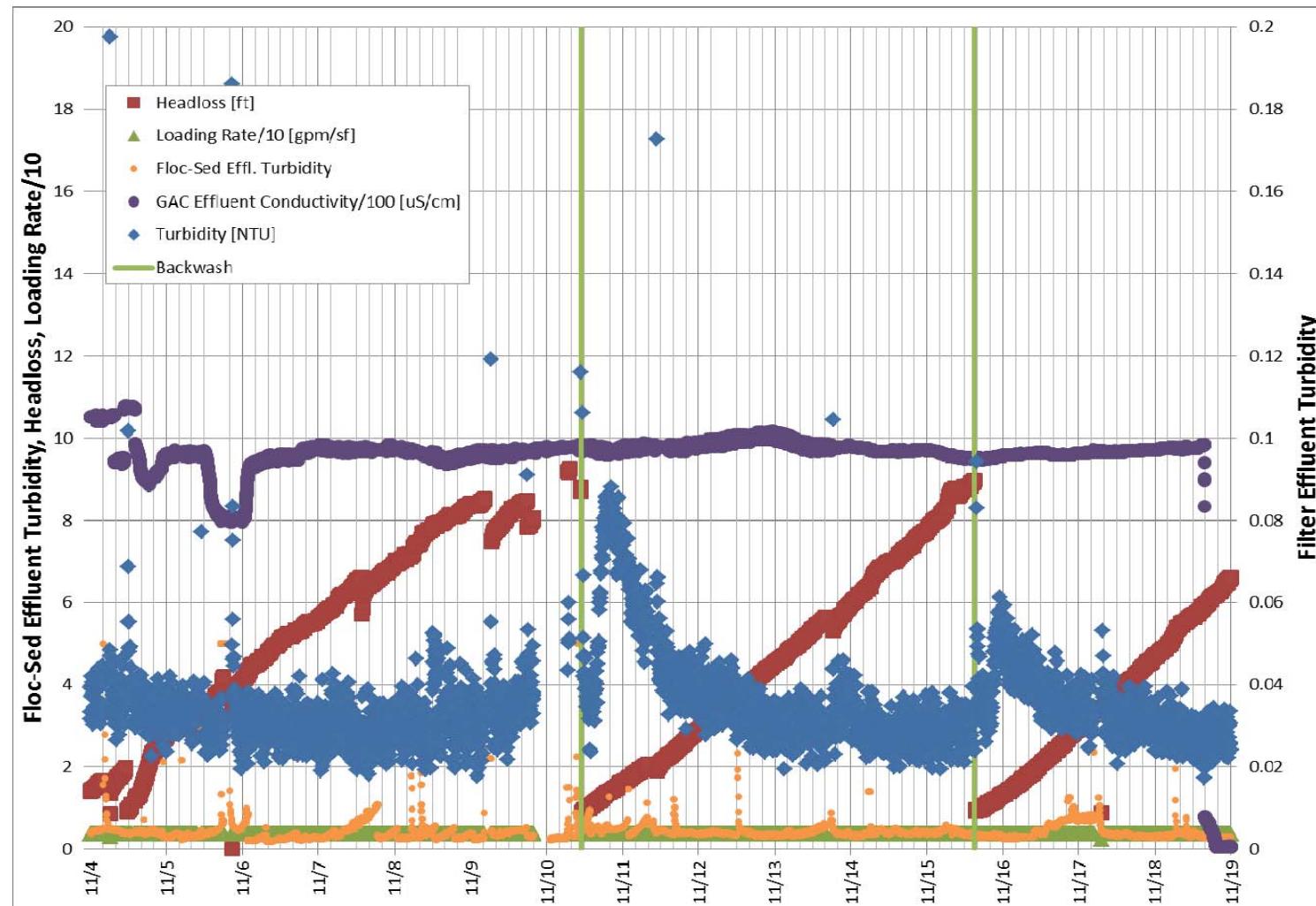
**GAC High**



## BAC and GAC

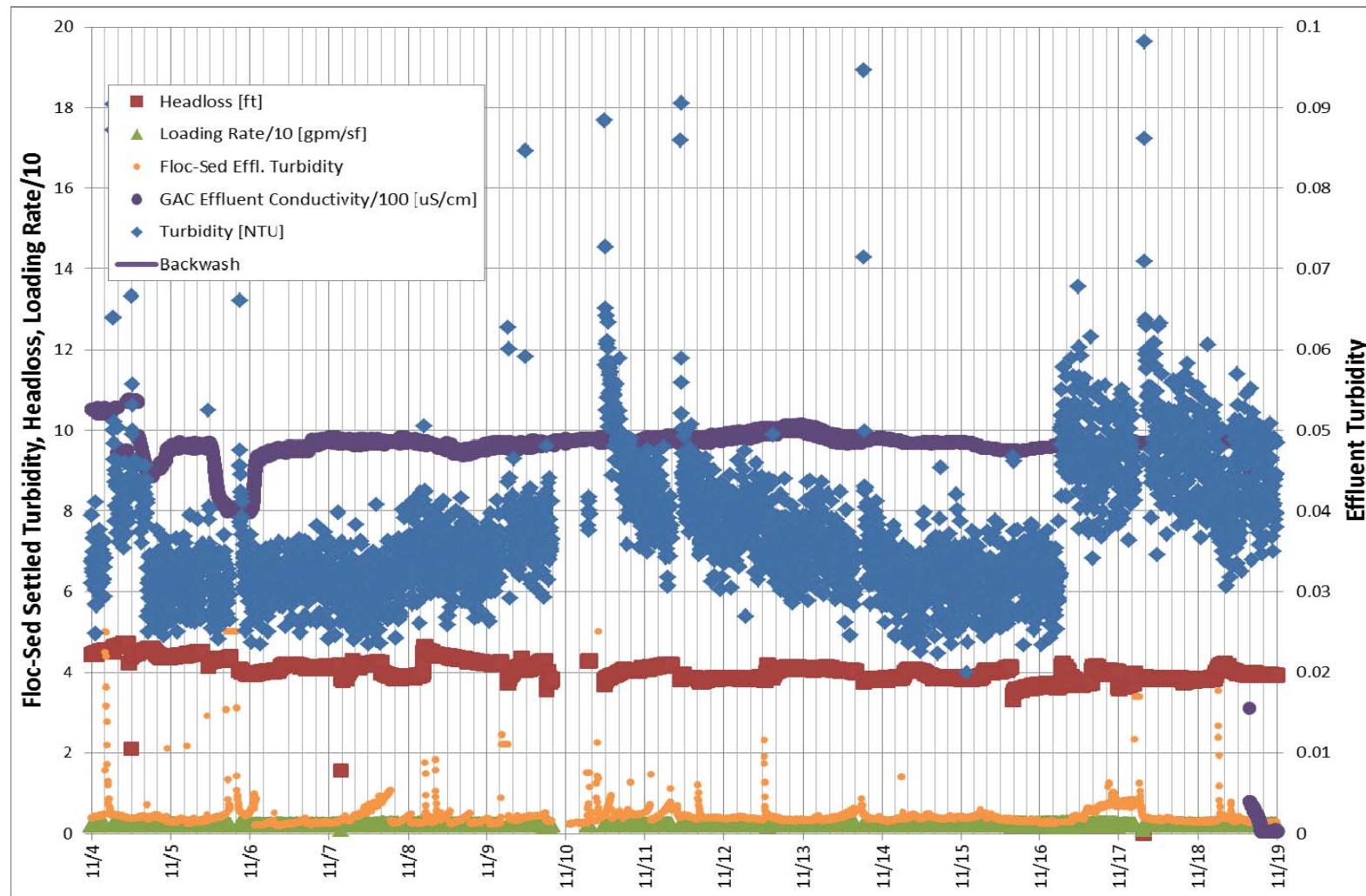
### Overall performance

**BAC Low**



## BAC and GAC Overall performance

**GAC Low**





## BAC and GAC

### Detailed review of effluent turbidity

BAC High	
n	40962
5%	0.02
50%	0.04
95%	0.08

GAC High	
n	40092
5%	0.03
50%	0.05
95%	0.10

BAC Low	
n	41220
5%	0.02
50%	0.04
95%	0.10

GAC Low	
n	40373
5%	0.03
50%	0.05
95%	0.17

- Turbidity was below 0.1 NTU during most of the operation
- 2-log virus, 2.5-log *Giardia*, and 3-log *Cryptosporidium* removal achieved according to Long Term 2 Enhanced Surface Water Treatment Rule
- Turbidity less than 0.15 NTU in at least 95% of values
- No measurement greater than 0.3 NTU for 2 consecutive samples in 15 min



## BAC and GAC

### Backwash summary

#### **BAC and GAC Backwash regimen**

- BAC Chlorinated backwash (0.2 mg/L residual)
- Backwashed if 0.1 NTU and headloss 10 ft

#### **Typical Filter Run Time**

- BAC High : 2 days
- BAC Low : 4 days
- GAC High & Low : 1-2 months depending on headloss

#### **Average UFRV (gal/sf)**

- BAC High: 21,500 gal/sf
- BAC Low: 23,500 gal/sf

#### **Filter Ripening Volume (target <150 gal/sf)**

- BAC High : 100 gal/sf
- BAC Low : 83 gal/sf

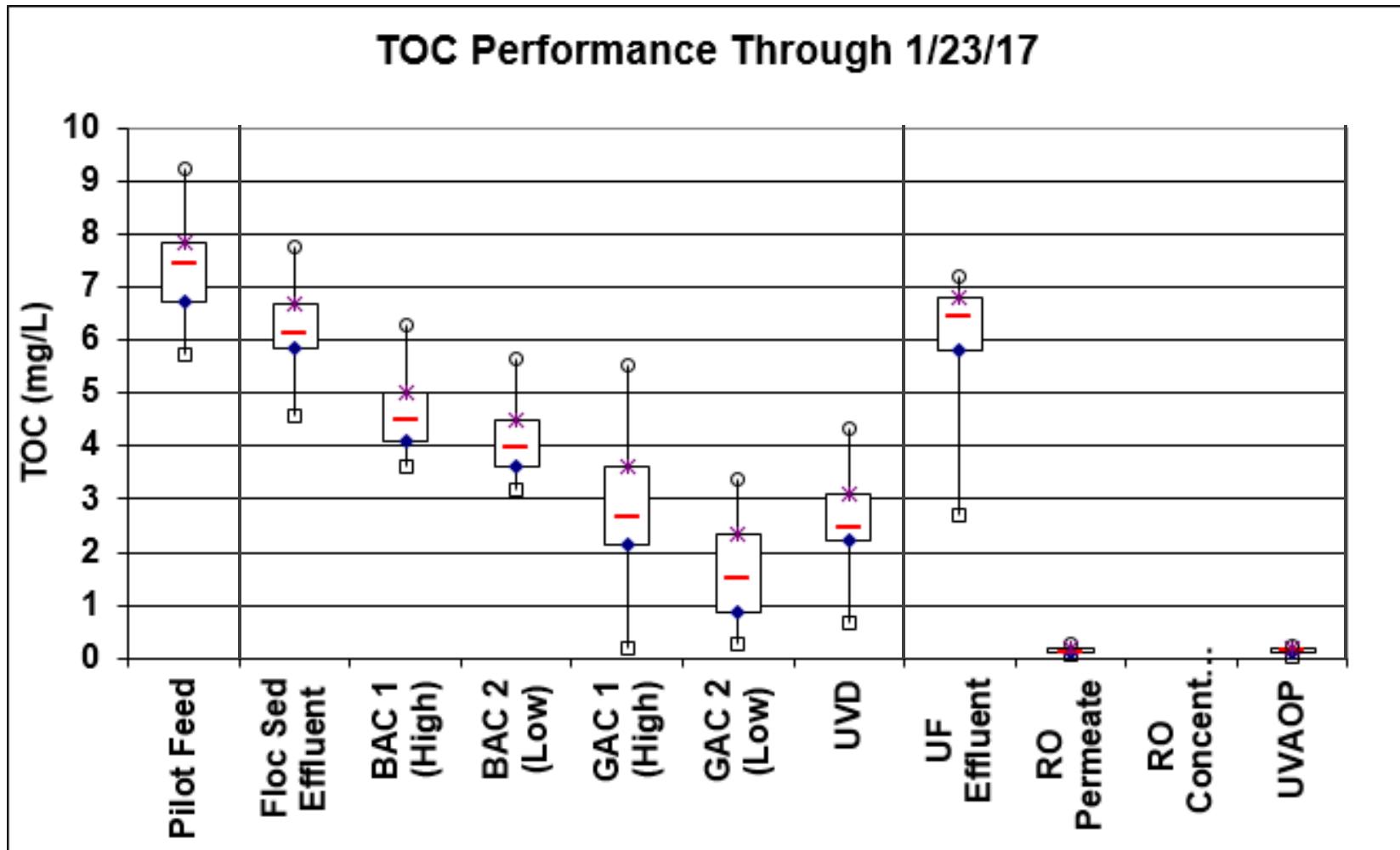


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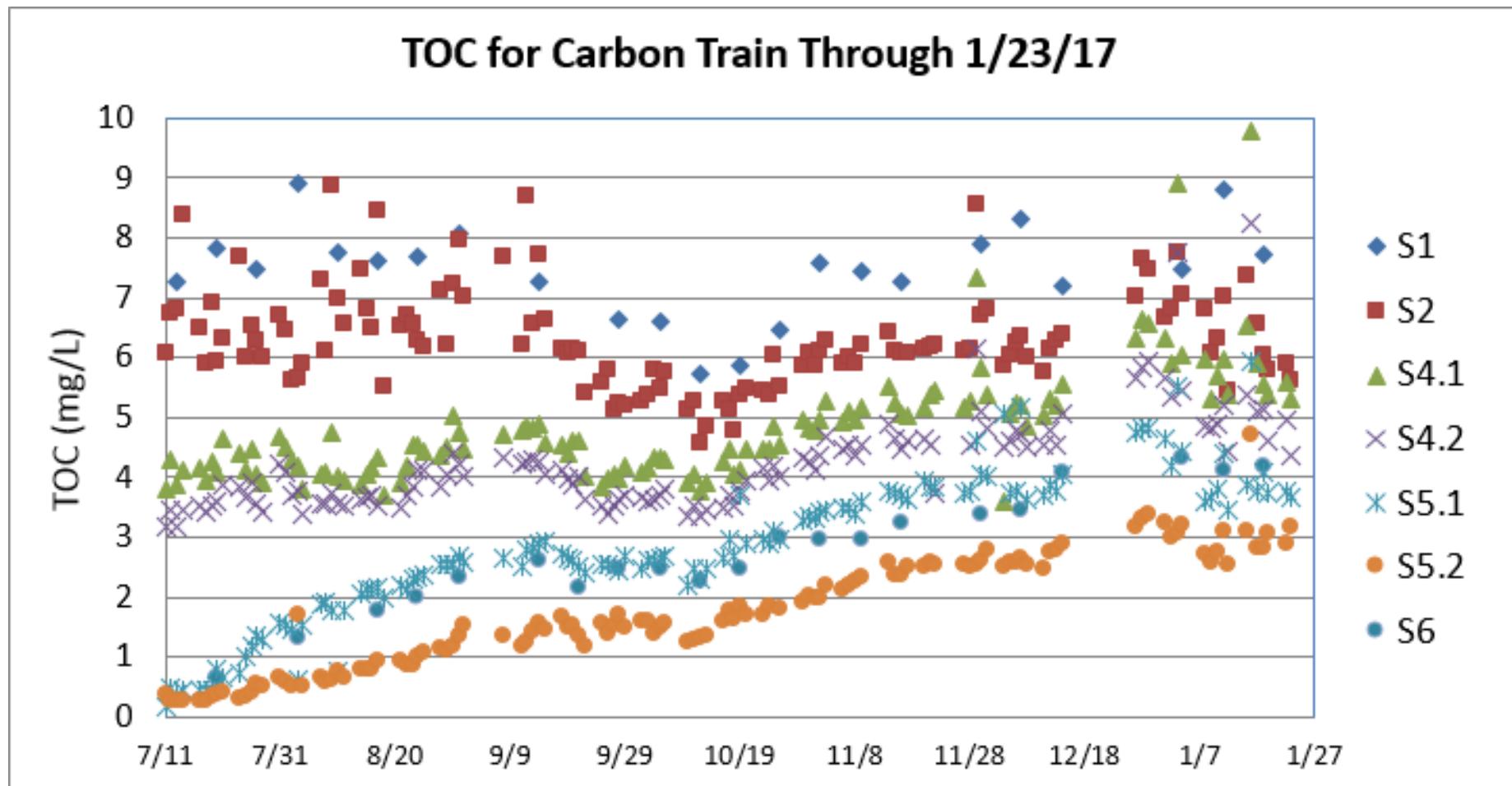
## Analytical Review Outline

- TOC
- Nutrients
- Ions
- EPA MCLs
- Pathogens
- CECs

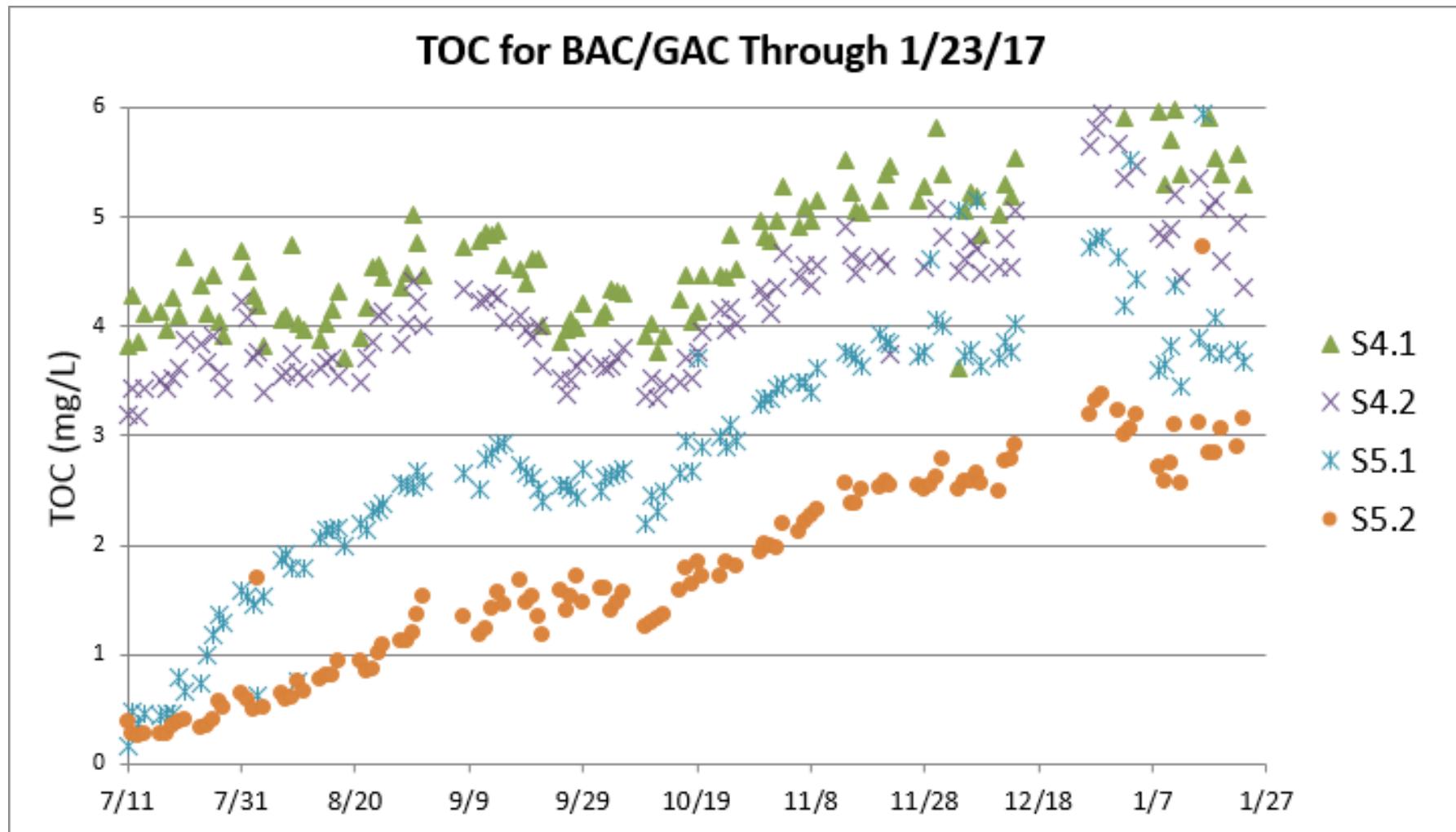
## TOC Performance



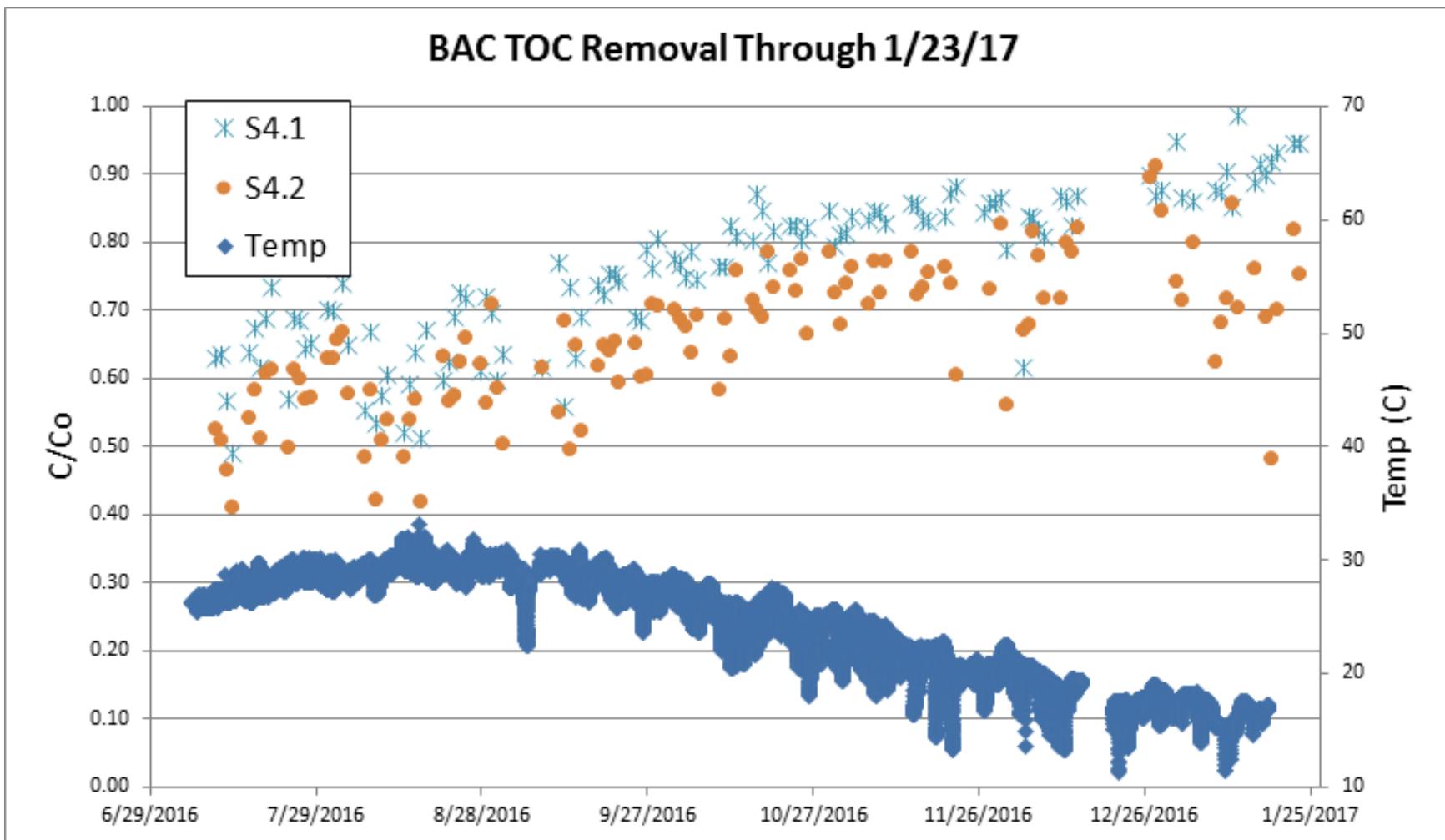
## TOC Performance: GAC Train



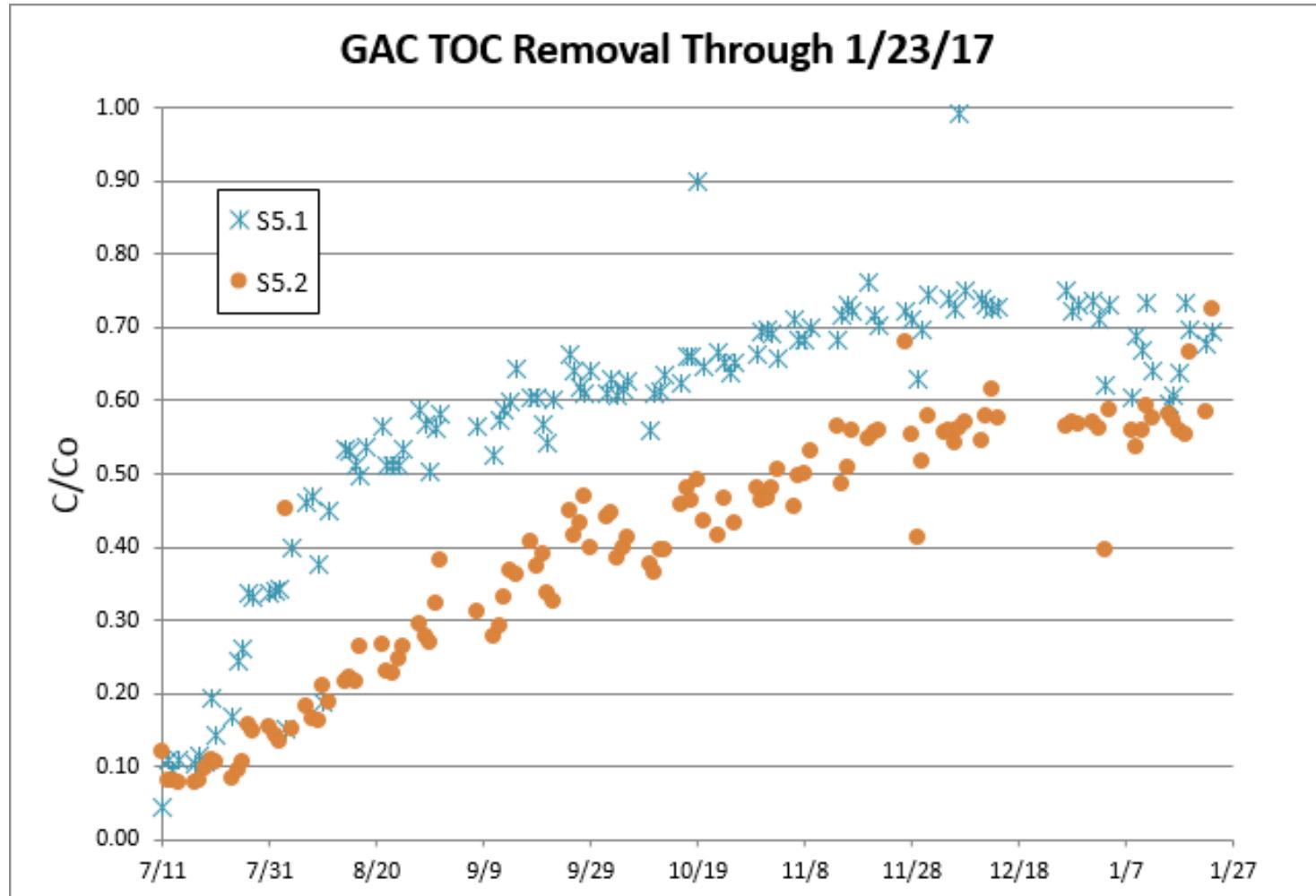
## TOC Performance: GAC Train



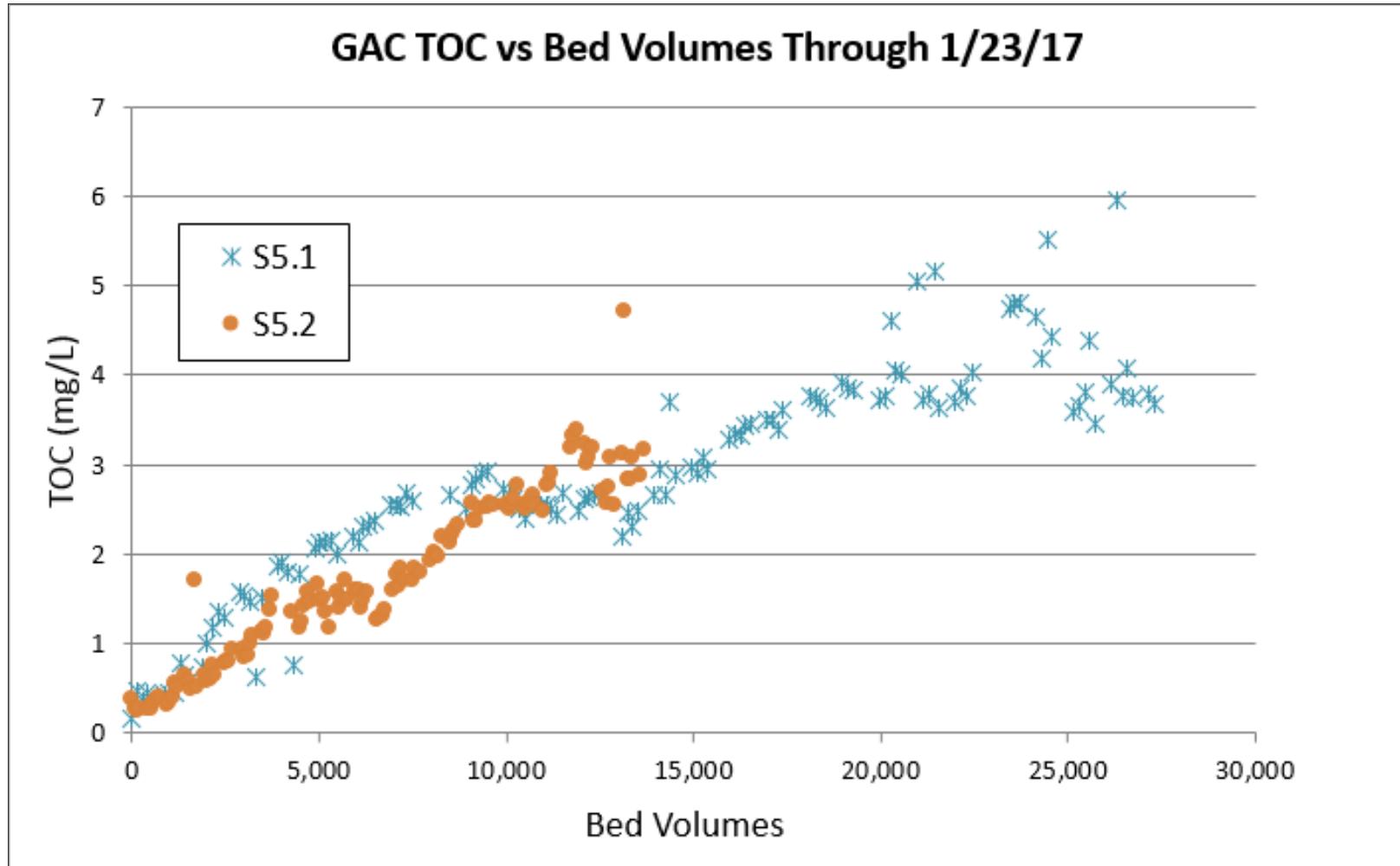
## TOC Performance: GAC Train



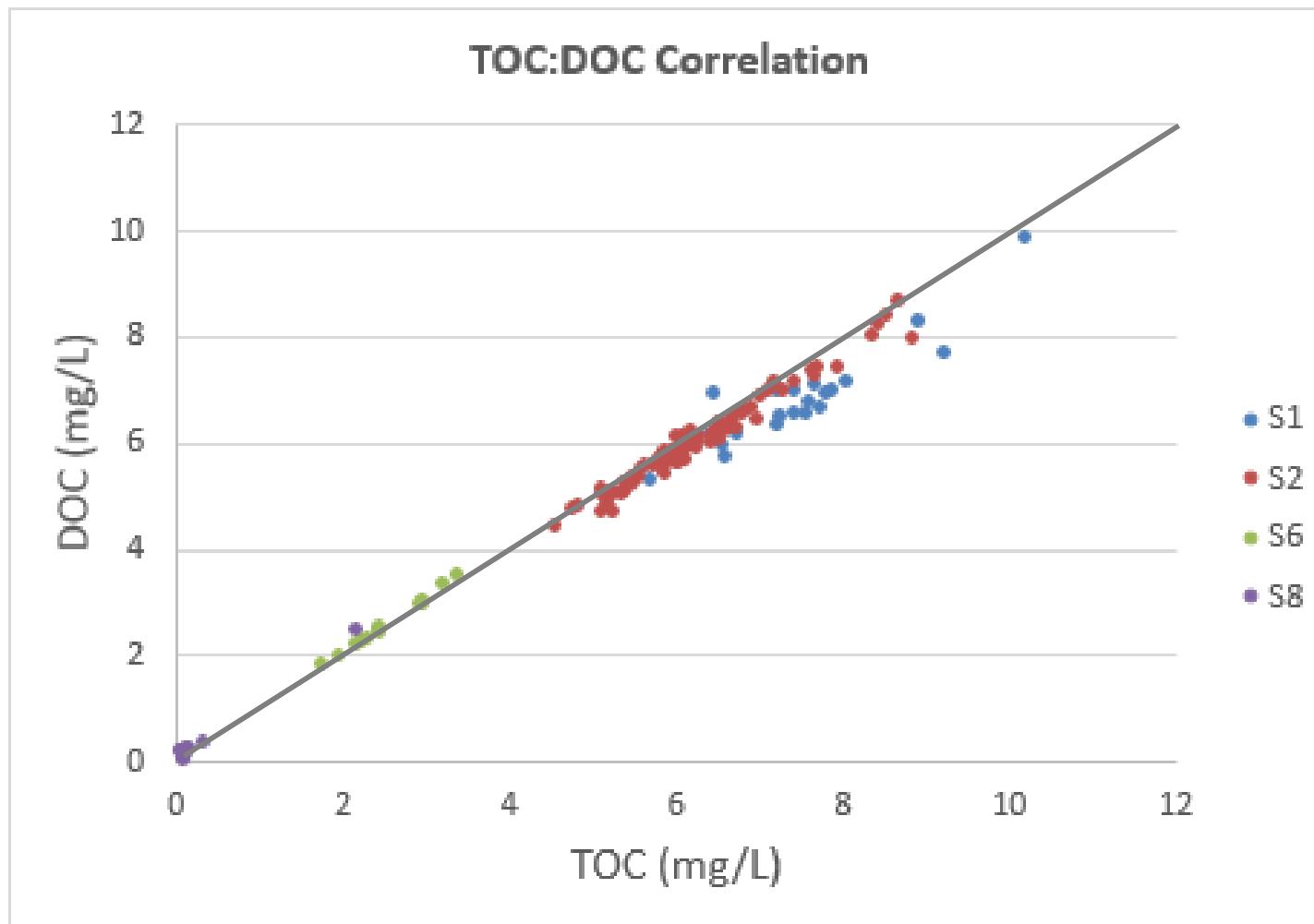
## TOC Performance: GAC Train



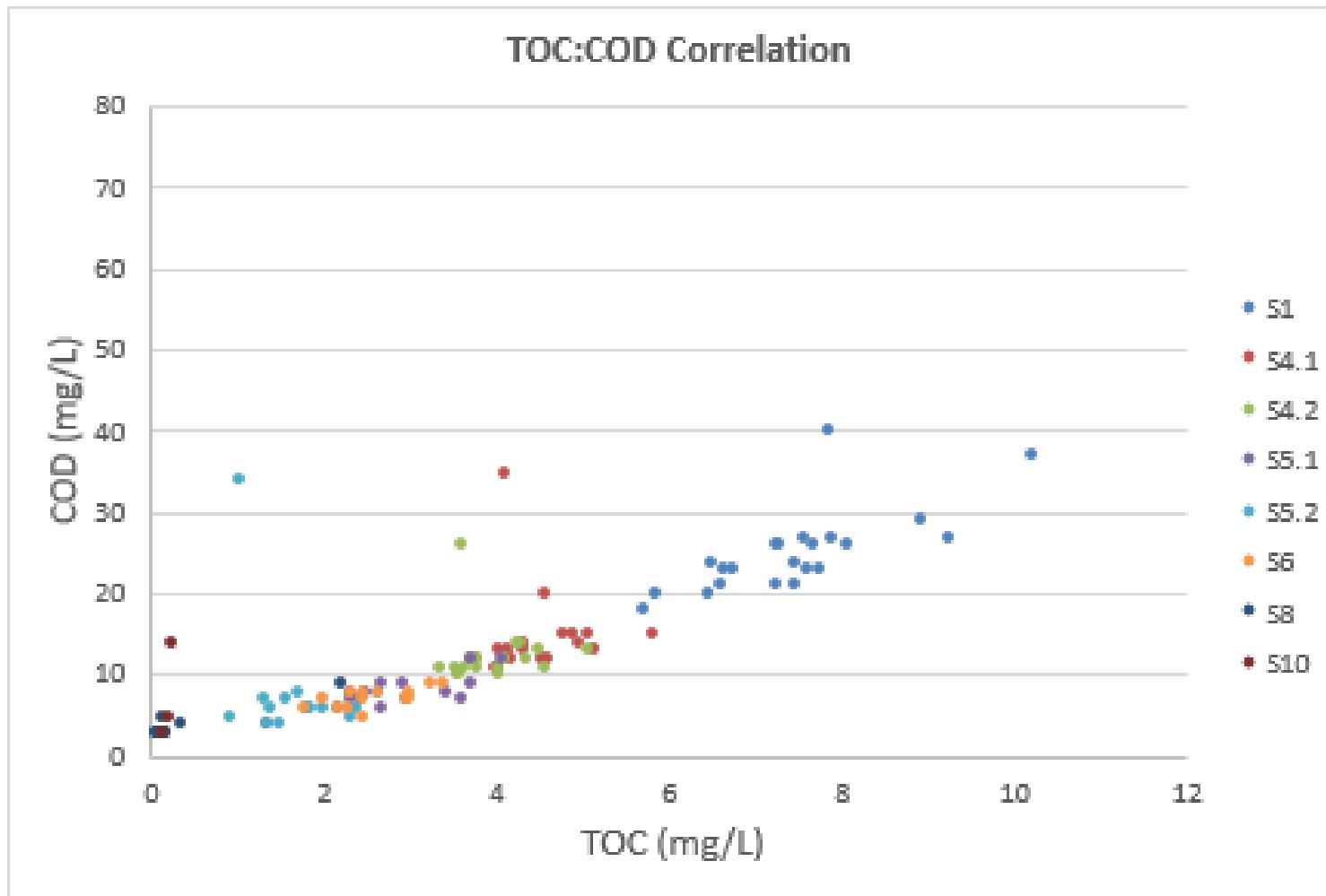
## TOC Performance: GAC Train



## TOC:DOC Correlation

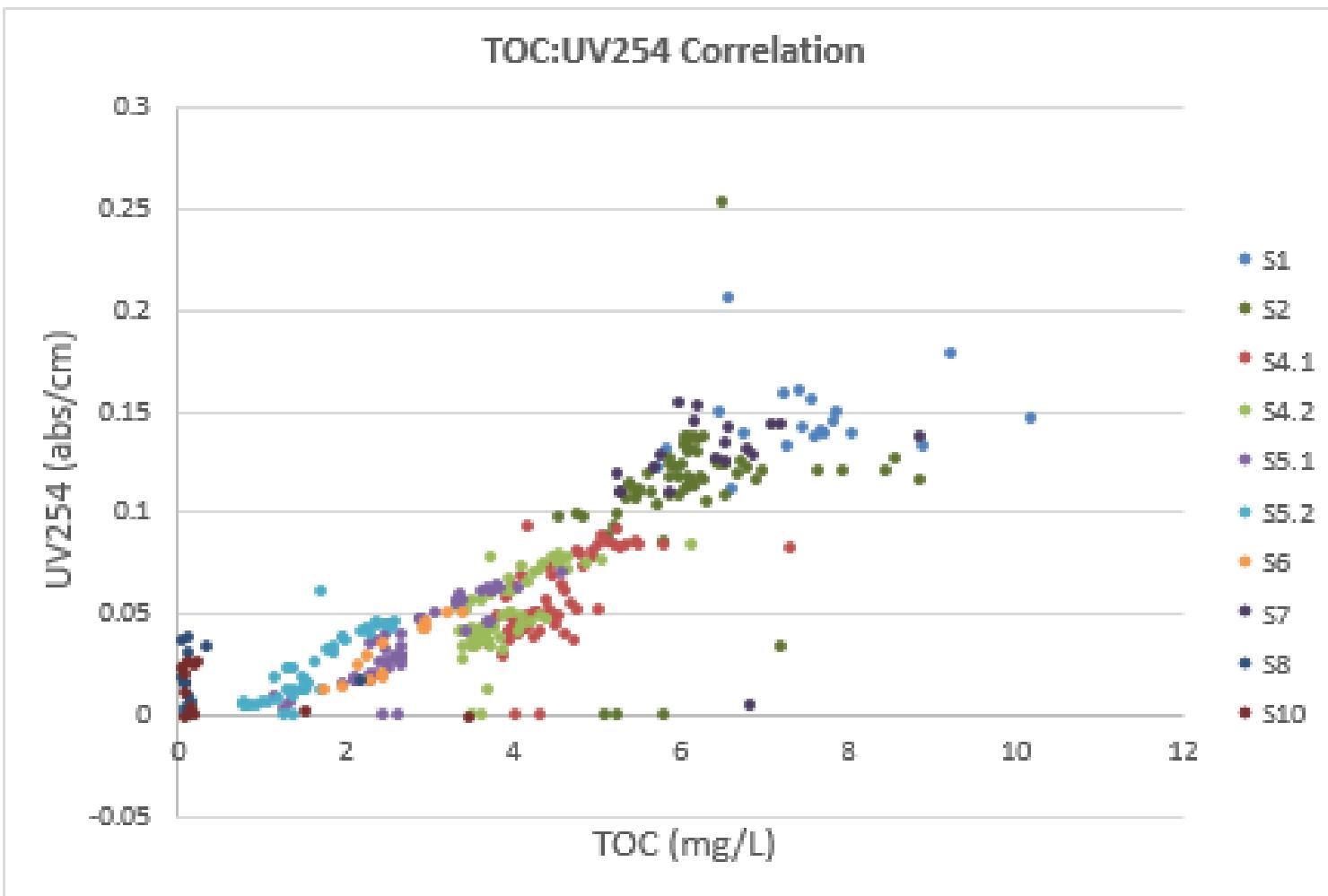


## TOC:COD Correlation



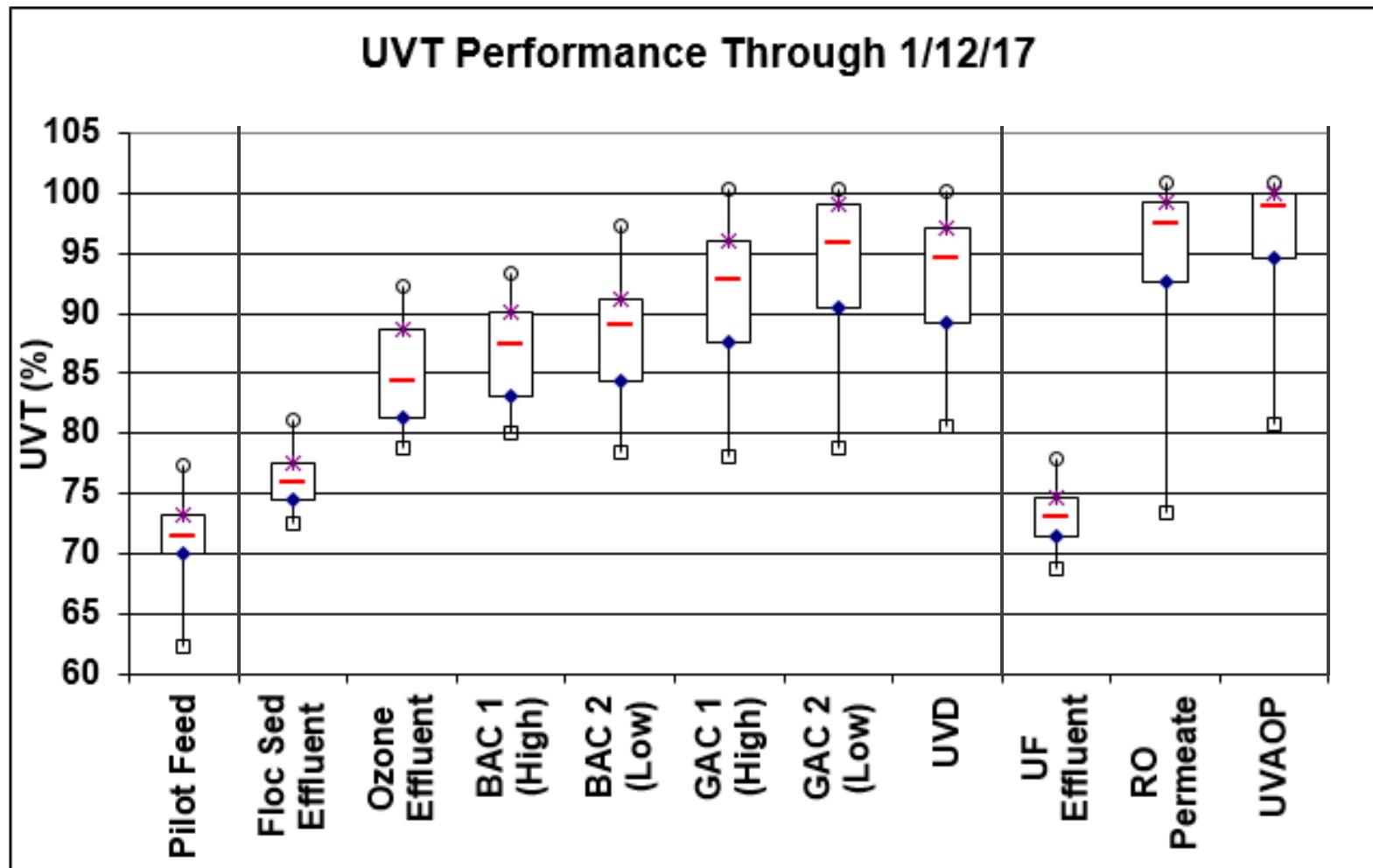
Regression of S5.1/S5.2/S6 data → COD = 10 mg/L gives TOC estimate = 4.05 mg/L  
( $R^2 = 0.55$ )

## TOC:UV254 Correlation

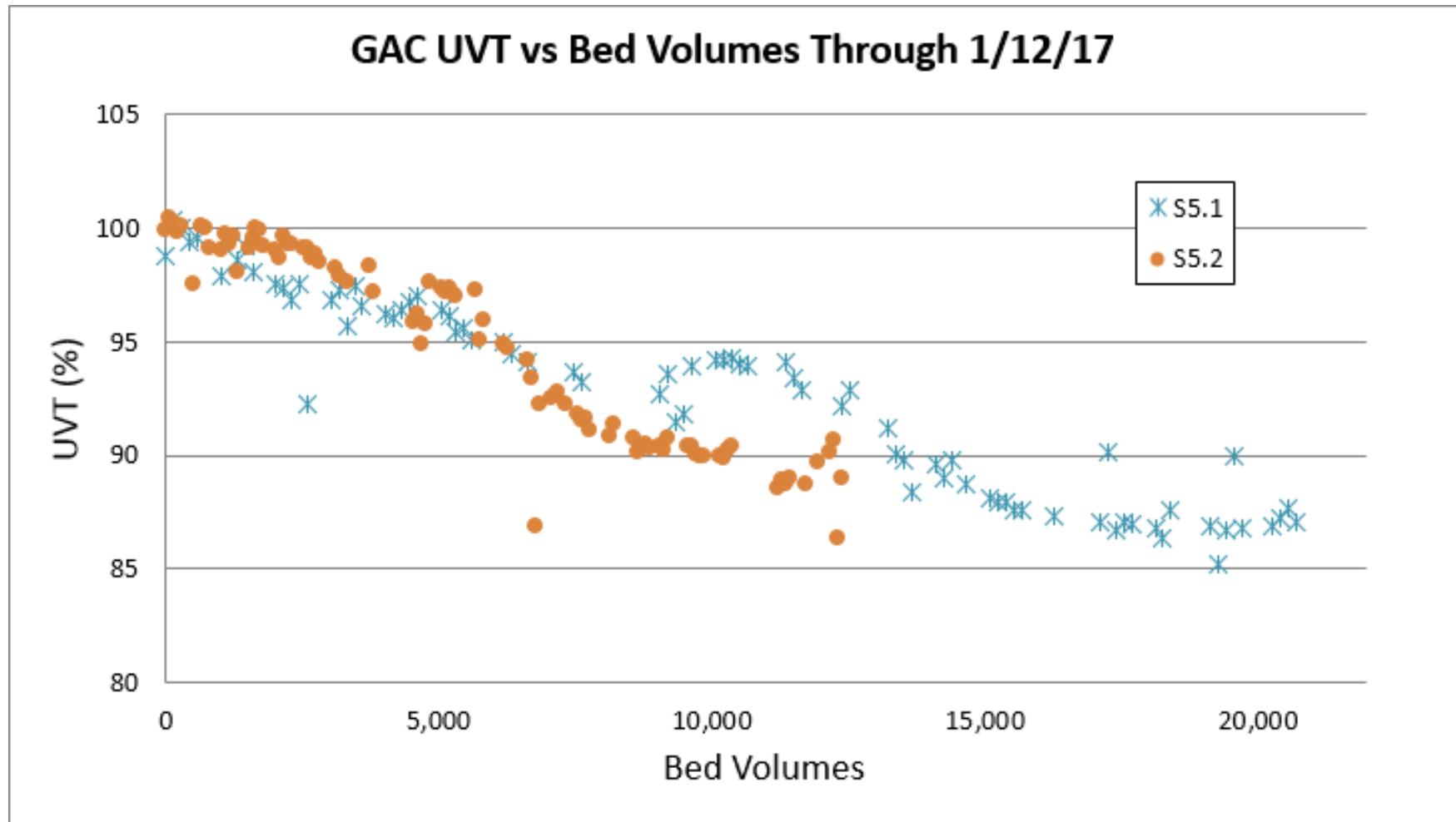


Regression of S5.1/S5.2/S6 data → TOC = 4.05 mg/L gives estimated UV254 = 0.0613 abs/cm and UVT = 86.5%

## UVT Performance



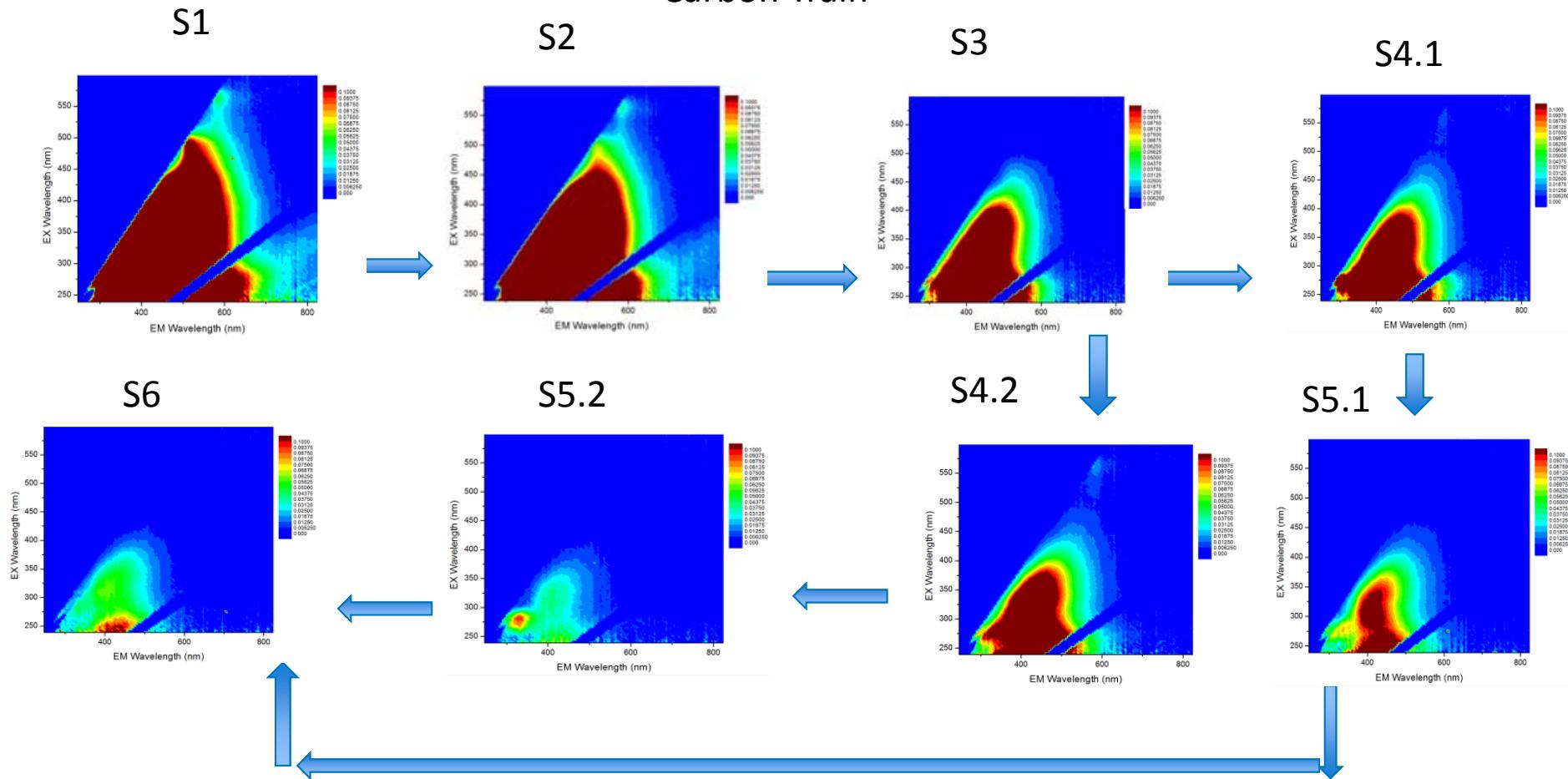
## GAC UVT Performance



# Fluorescence Spectroscopy

## Total Fluorescence through treatment process

### Carbon Train

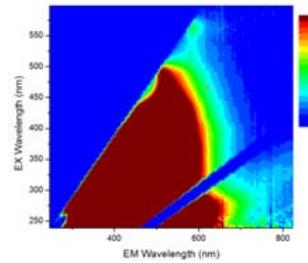


# Fluorescence Spectroscopy

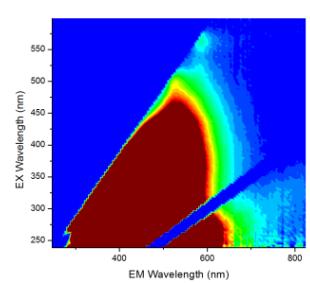
Total Fluorescence through treatment process

## Membrane Train

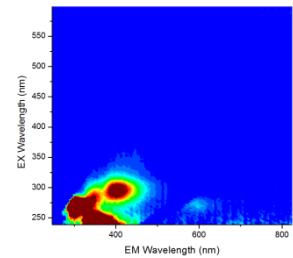
S1



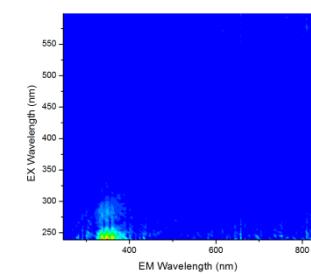
S7



S8



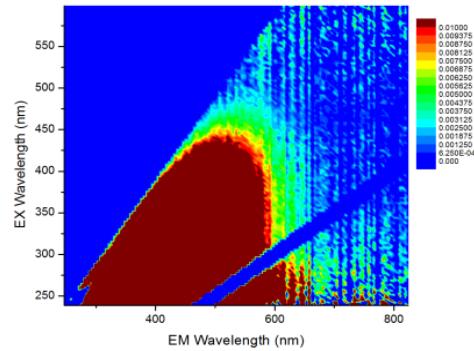
S10



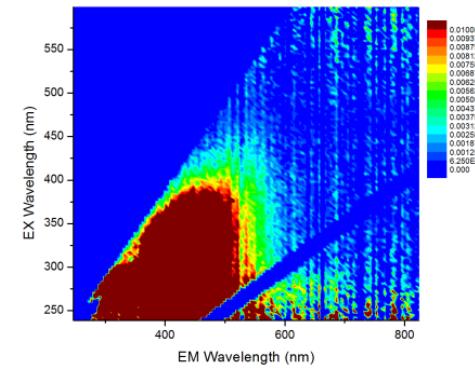
# Fluorescence Spectroscopy

## Total Fluorescence through treatment process zoomed

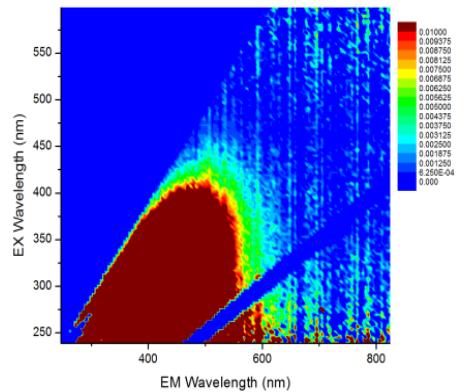
S5.1



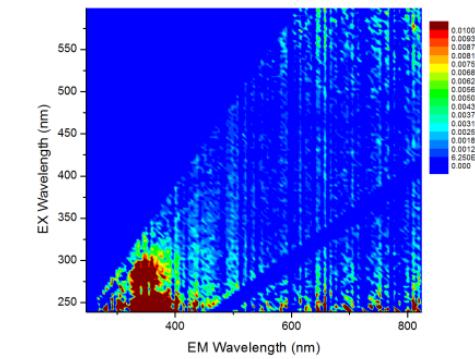
S5.2



S6



S10

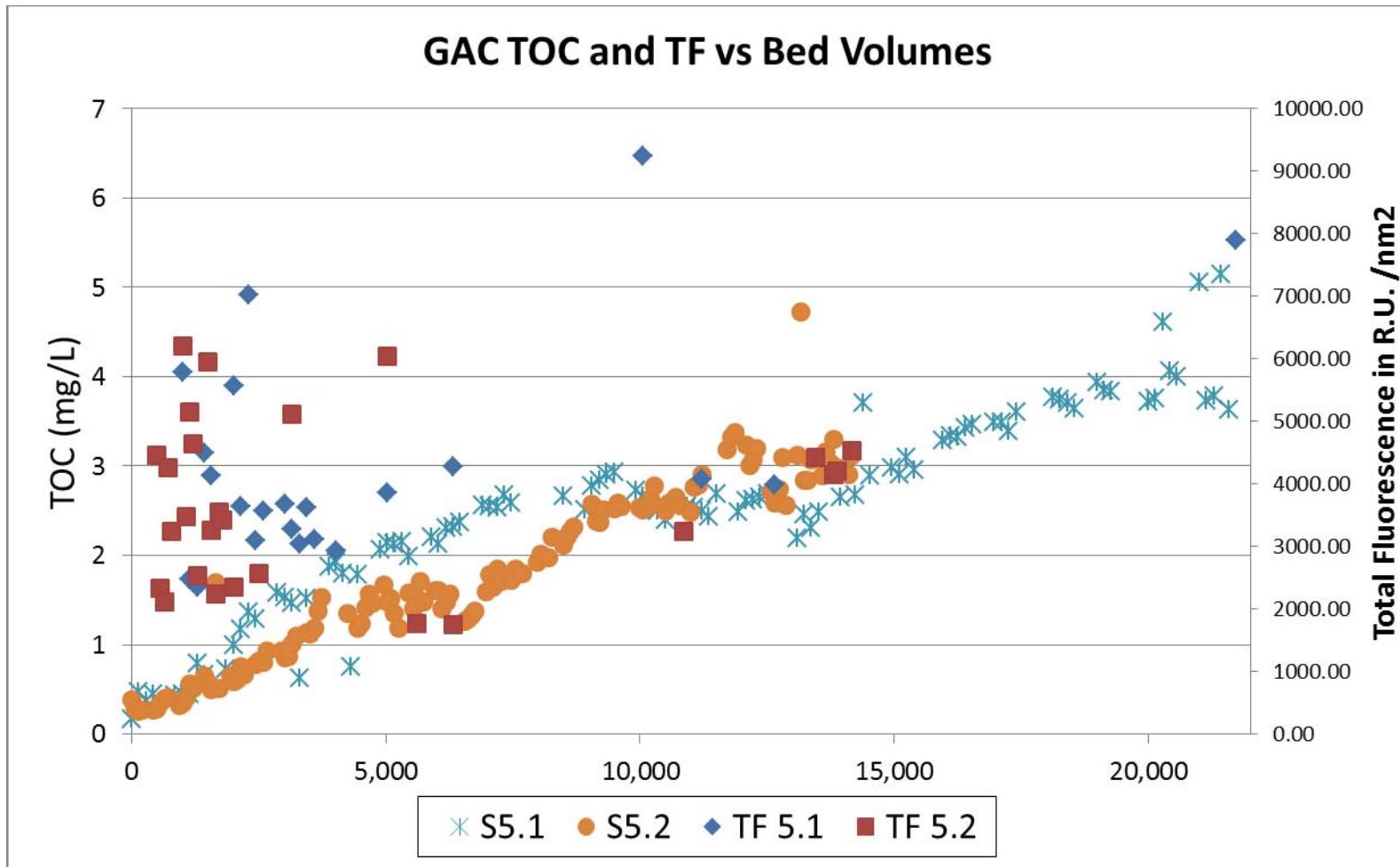


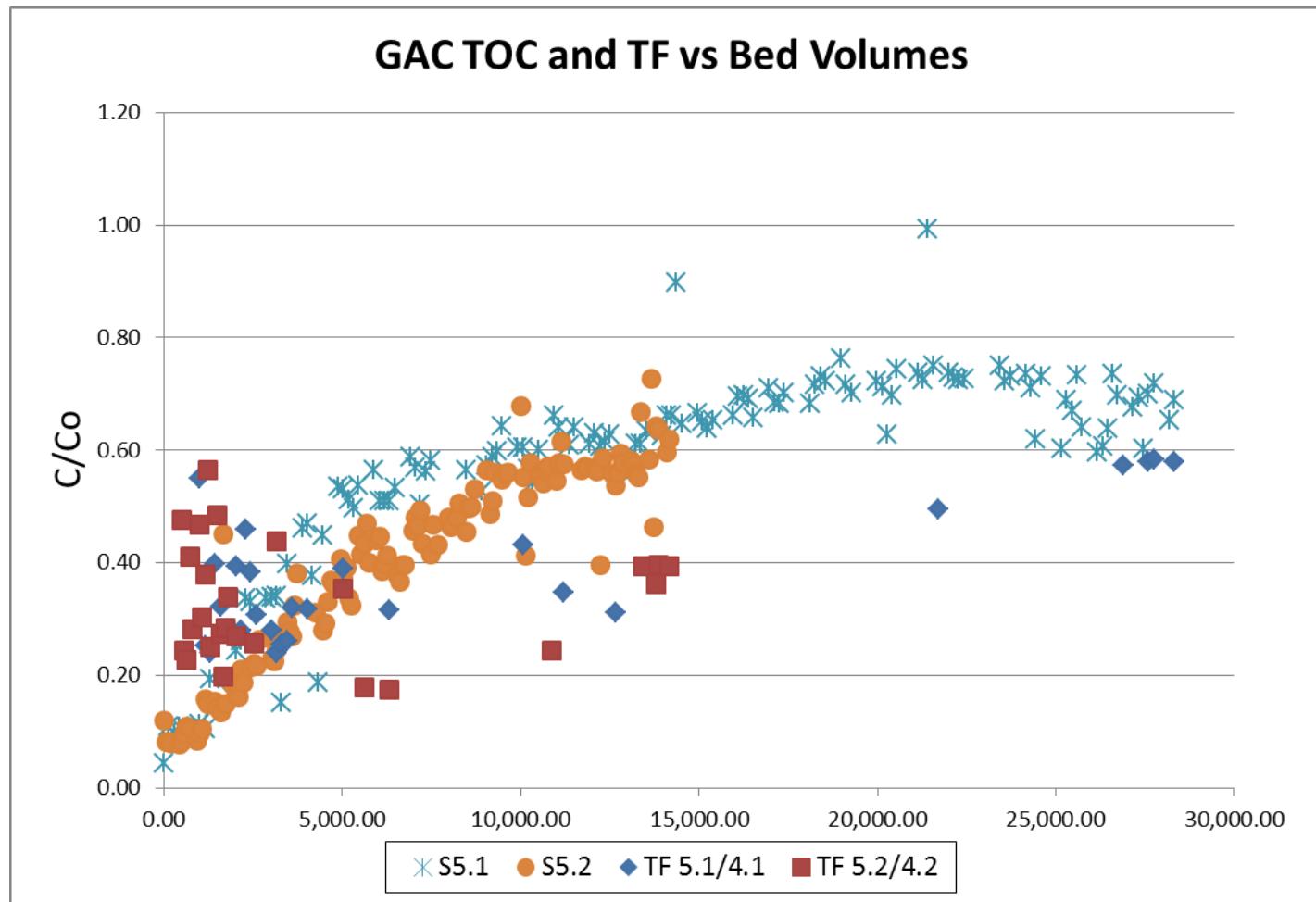


## Fluorescence Spectroscopy

9-Dec-2016	Corrected TF (R.U. nm <sup>2</sup> )	% UVT
Pilot Feed	103725	72.48
Floc/Sed	81835	75.86
Ozone	19020	81.84
BAC High	15951	83.49
BAC Low	13259	84.69
GAC High	7889	87.04
GAC Low	3248	90.42
UVD	4603	88.64
UF	85218	71.95
RO	4787	90.21
UVAOP	1061	94.62

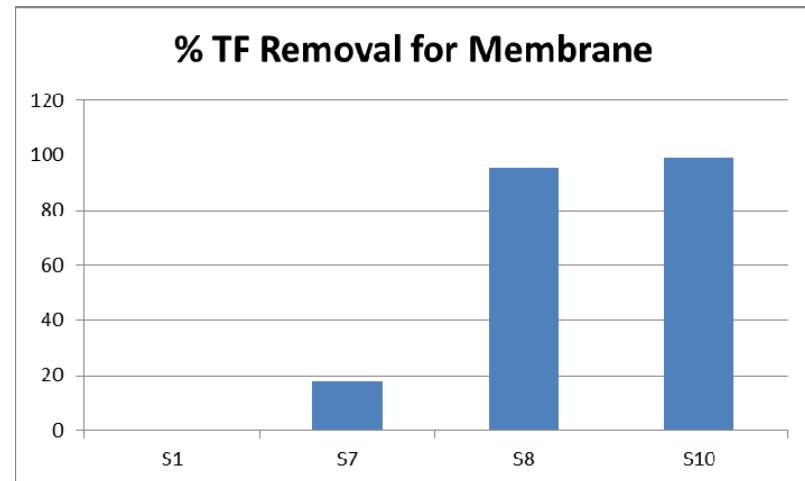
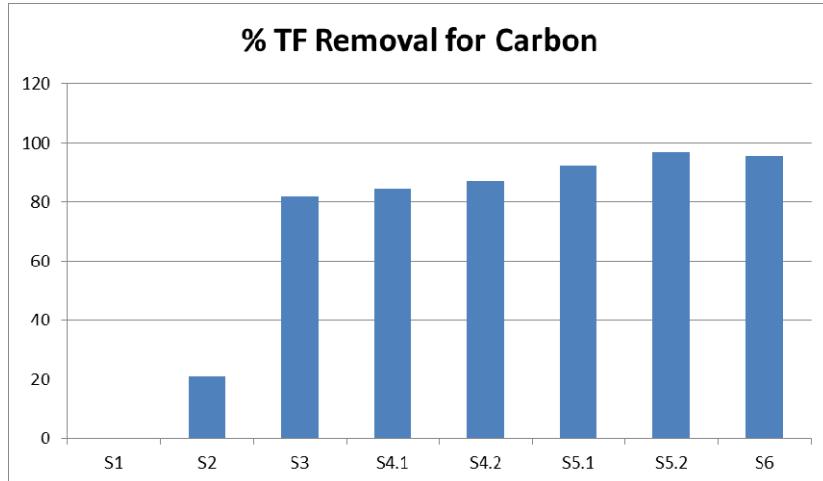
## Total Fluorescence and TOC



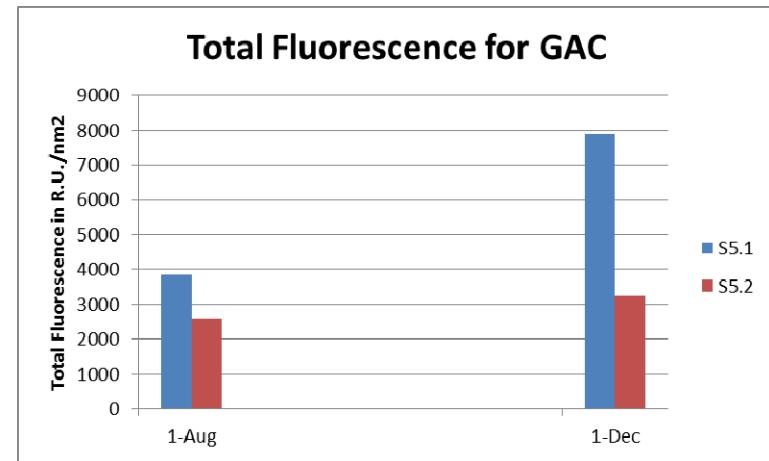


## Fluorescence Spectroscopy

### Total Fluorescence through treatment process

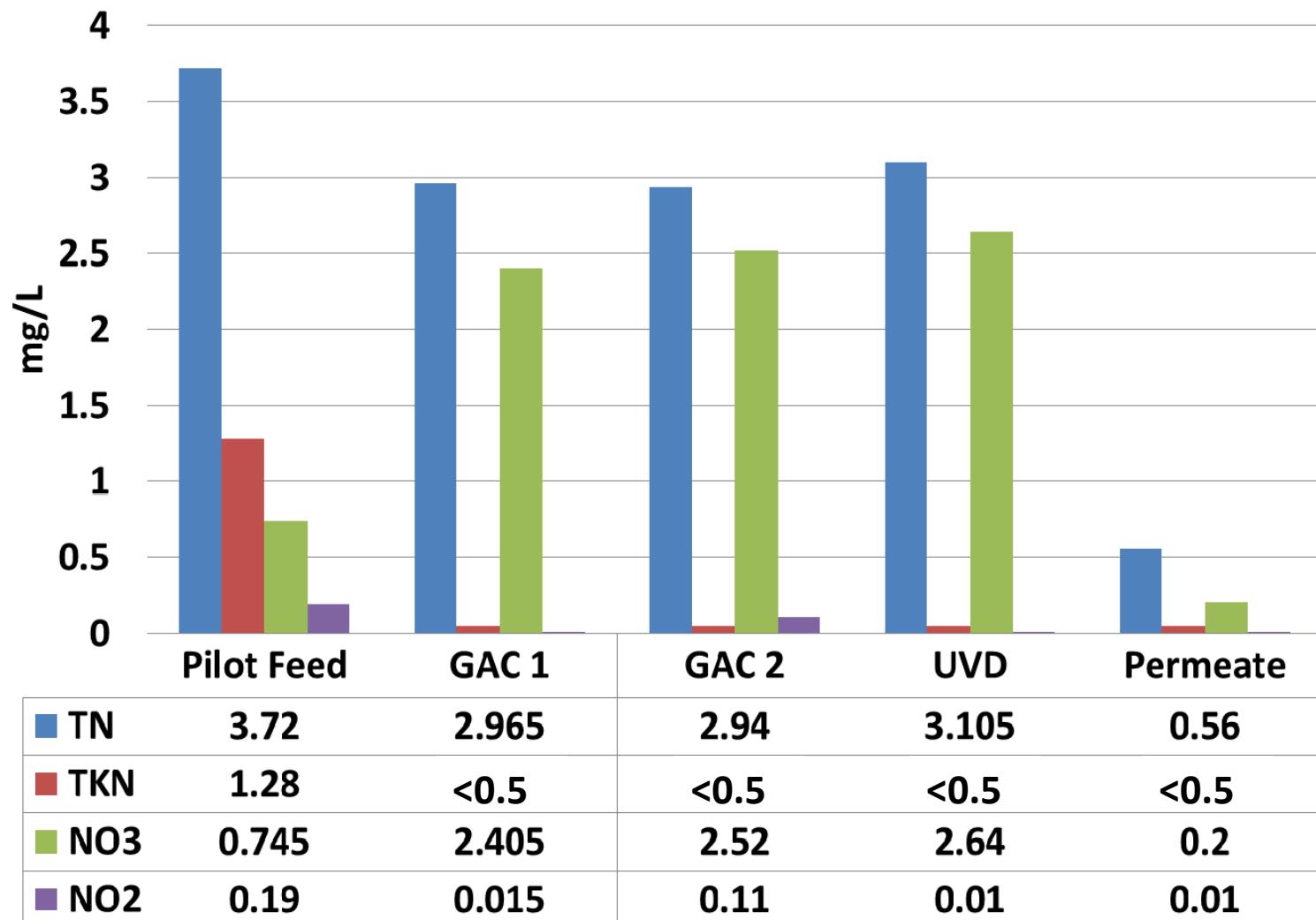


- Almost 100% removal seen in both trains
- Carbon was able to achieve similar removal as RO
- GAC utilization over time results in increased in TF values



## Nitrogen (50%-ile)

Average of Total Nitrogen



## Phosphorus

- Pilot feed 50% values:
  - TP: 0.37 mg/L
  - OP: 0.18 mg/L
- Non-detect TP in 100% of UVD and RO effluent
- UVD effluent 50%: OP = 0.03 mg/L
- Potential to add Phosphoric Acid to BAC influent

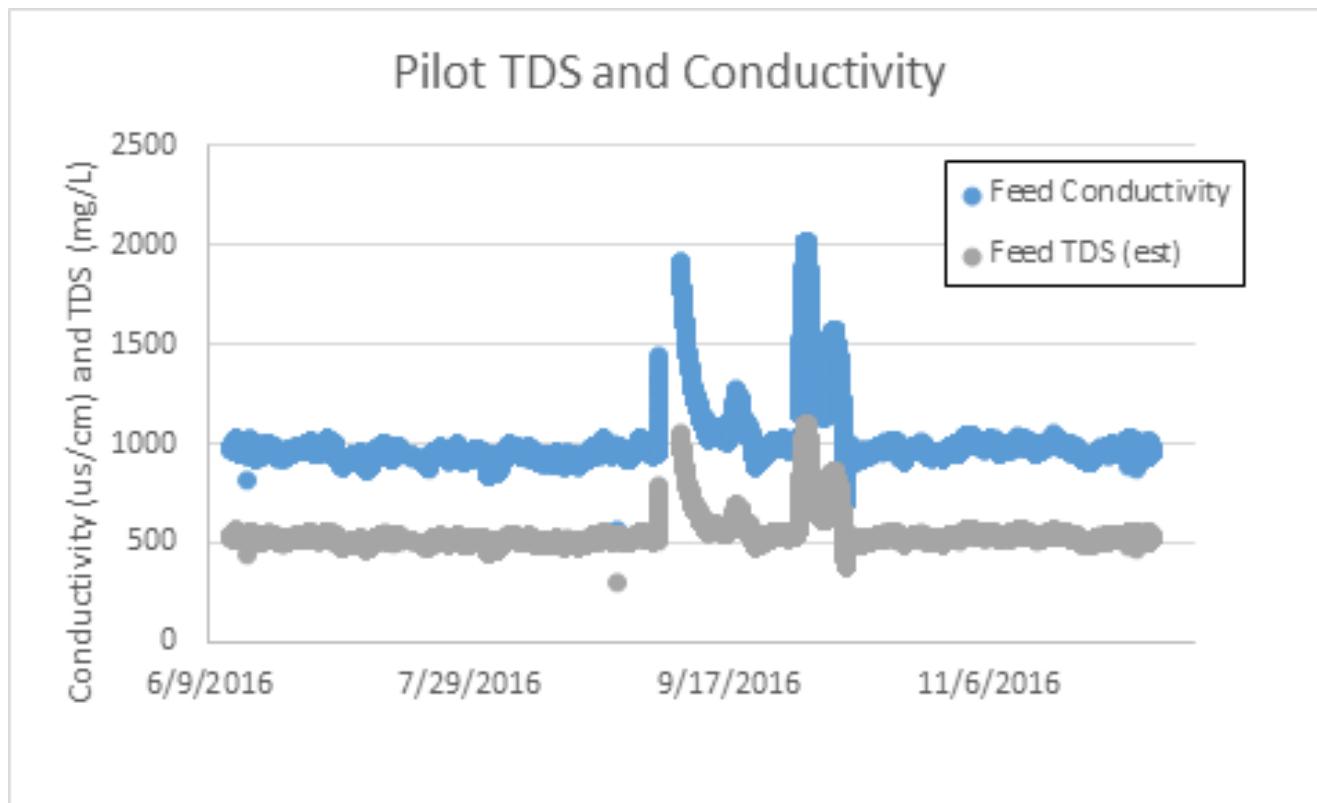


## 50%-ile Ion Concentrations

Parameter	Pilot Feed	UVD Effluent	RO Effluent	RO Concentrate
TDS (mg/L)	541	552	12	2,600
Alkalinity (mg/L CaCO <sub>3</sub> )	109	109	10	575
Hardness (mg/L CaCO <sub>3</sub> )	194	185	0.5	906
Na (mg/L)	118	128	3	525
Ca (mg/L)	57	56	0.1	257
Mg (mg/L)	10	10	0.1	47
Cl (mg/L)	159	171	4	806
SO <sub>4</sub> (mg/L)	94	95	1	430

## TDS and Conductivity

- Approximate correlation:  $TDS = 0.550 * \text{Cond}$





## Primary MCLs

YR Pilot Plant Performance and Drinking Water Primary MCLs

Parameter	Primary MCL mg/L	Carbon Train				Membrane Train			
		Max	Min	Average	Sample Location	Max	Min	Average	Sample Location
Barium	2	0.008	0.008	0.008	S6	<0.005	<0.005	<0.005	S10
Chlordane	0.002	<0.00002	<0.00002	<0.00002	S6	<0.00002	<0.00002	<0.00002	S10
Endrin	0.002	<0.00001	<0.00001	<0.00001	S6	<0.00001	<0.00001	<0.00001	S10
Heptachlor	0.0004	<0.00001	<0.00001	<0.00001	S6	<0.00001	<0.00001	<0.00001	S10
Heptachlor Epoxide	0.0002	<0.00001	<0.00001	<0.00001	S6	<0.00001	<0.00001	<0.00001	S10
Lindane	0.05	<0.00001	<0.00001	<0.00001	S6	<0.00001	<0.00001	<0.00001	S10
Methoxychlor	0.04	<0.00001	<0.00001	<0.00001	S6	<0.00001	<0.00001	<0.00001	S10
Toxaphene	0.003	<0.00005	<0.00005	<0.00005	S6	<0.00005	<0.00005	<0.00005	S10
PCBs- AR1016	0.0005	<0.0001	<0.0001	<0.0001	S6	<0.0001	<0.0001	<0.0001	S10
PCBs- AR1221	0.0005	<0.0001	<0.0001	<0.0001	S6	<0.0001	<0.0001	<0.0001	S10
PCBs- AR1232	0.0005	<0.0001	<0.0001	<0.0001	S6	<0.0001	<0.0001	<0.0001	S10
PCP	0.0007	<0.001	<0.0001	<0.0001	S6	<0.0001	<0.001	<0.001	S10

- Though a few MCL contaminants were detected, none of the more than 90 parameters exceeded the PMCL. {None were even close. Vast majority were not detected}
- As more data are generated, an updated table will be provided.

## Disinfection Byproducts

- TTHMs and HAA5 pilot performance

	Parameter	Primary MCL (mg/L)	Carbon Train				Membrane Train			
			Max	Min	Average	Sample Location	Max	Min	Average	Sample Location
TTHM	Bromodichloromethane	0.08	0.008	<0.002	0.006	S6	<0.002	<0.002	<0.002	S10
	Bromoform		0.03	<0.002	0.018	S6	<0.002	<0.002	<0.002	S10
	Chloroform		0.002	<0.002	0.002	S6	<0.002	<0.002	<0.002	S10
	Dibromochloromethane		0.02	<0.002	0.012	S6	<0.002	<0.002	<0.002	S10
HAAs	Dichloroacetic acid	0.06	0.002	<0.001	0.002	S6	<0.001	<0.001	<0.001	S10
	Trichloroacetic acid		<0.001	<0.001	<0.001	S6	<0.001	<0.001	<0.001	S10
	Monochloroacetic acid		<0.002	<0.002	<0.002	S6	<0.002	<0.002	<0.002	S10
	Bromoacetic acid		0.003	<0.001	0.002	S6	<0.001	<0.001	<0.001	S10
	Dibromoacetic acid		0.01	<0.001	0.009	S6	<0.001	<0.001	<0.001	S10



## Pilot Performance: Secondary MCLs

Parameter	Unit	Value	Pilot Effluent Values			
			GAC: 50%	GAC: 99%	RO: 50%	RO: 99%
Aluminum	mg/L	0.05	<0.04	<0.04	<0.04	<0.04
Chloride	mg/L	250	171	221	<4	<4
Color	color units	12	2	5	1	2
Copper	mg/L	1	<0.5	<0.5	<0.5	<0.5
Corrosivity		Non-corrosive	N/A	N/A	N/A	N/A
Fluoride	mg/L	2	0.6	0.7	<0.1	<0.1
Foaming agents	mg/L	0.5	N/A	N/A	N/A	N/A
Iron	mg/L	0.3	<0.02	0.05	<0.02	<0.02
Manganese	mg/L	0.05	<0.01	0.01	<0.01	<0.01
Odor	TON	3	N/A	N/A	N/A	N/A
pH	pH unit	6.5 - 8.5	7.5 - 7.7	7.5 - 7.7	7.5 - 7.7	7.5 - 7.7
Silver	mg/L	0.1	<0.005	<0.005	<0.005	<0.005
Sulfate	mg/L	250	95	107	<1.0	1.6
TDS	mg/L	500	541	635	12	29
Zinc	mg/L	5	<0.03	<0.03	<0.03	<0.03



## Pilot Performance: Health Advisory Limits

Chemical	Criterion	Carbon-based Train Conc.	Membrane-based Train Conc.	Notes
1,4-Dioxane	1 µg/L	0.26-0.39 µg/L <sup>1</sup>	<0.07 µg/L <sup>2</sup>	CCL3; CA Notification Limit
17-β-estradiol	TBD (ng/L range)	<0.005 µg/L <sup>3</sup>	<0.005 µg/L <sup>4</sup>	CCL3
DEET	200 µg/L	<0.010 µg/L <sup>3</sup>	<0.010-0.012 µg/L <sup>4</sup>	MN Health Guidance Value
Ethinyl Estradiol	TBD (ng/L range)	<0.005 µg/L <sup>3</sup>	<0.005 µg/L <sup>4</sup>	CCL3
NDMA	10 ng/L	<0.2-2.5 ng/L <sup>5</sup>	<2-7.9 ng/L <sup>6</sup>	CCL3; CA Notification Limit
Perchlorate	6 µg/L	< 4 µg/L <sup>7</sup>	< 4 µg/L <sup>7</sup>	CA Notification Limit
PFOA + PFOS	70 ng/L	<60 ng/L	<60 ng/L	USEPA Health Advisory
TCEP	5 µg/L	<0.010 µg/L <sup>3</sup>	<0.010 µg/L <sup>4</sup>	MN Health Guidance Value

<sup>1</sup> Based on 6 samples in finished water

<sup>2</sup> Based on 1 sample in finished water

<sup>3</sup> Based on 12 samples in finished water

<sup>4</sup> Based on 9 samples in finished water

<sup>5</sup> Based on 2 samples in finished water

<sup>6</sup> Based on 20 samples in finished water

<sup>7</sup> Based in 10 samples in pilot feed; only 2 data points available in finished water for carbon (results <4 µg/L)

<sup>8</sup> Based on 4 samples in pilot feed; not sampling finished water



## Pilot Performance: Treatment Indicators

Chemical	Value <sup>1</sup>	Carbon-based Train Conc.	Membrane-based Train Conc.	Notes
Cotinine	1 µg/L	<0.010 µg/L <sup>2</sup>	<0.010 µg/L <sup>3</sup>	
Primidone	10 µg/L	Range: <0.005 – 0.0052 µg/L <sup>2</sup>	<0.005 µg/L <sup>3</sup>	CCL3; CA Notification limit CCL3
Phenyltoin	2 µg/L	<0.02 µg/L <sup>2</sup>	<0.02 µg/L <sup>3</sup>	MN Health guidance value
Meprobamate	200 µg/L	<0.005 µg/L <sup>2</sup>	<0.005 µg/L <sup>3</sup>	High occurrence in WWTP effluent
Atenolol	4 µg/L	<0.005 µg/L <sup>2</sup>	<0.005 µg/L <sup>3</sup>	
Carbamazepine	10 µg/L	<0.005 µg/L <sup>2</sup>	<0.005 µg/L <sup>3</sup>	Unique structure
Estrone	320 µg/L	<0.005 µg/L <sup>2</sup>	<0.005 µg/L <sup>3</sup>	Surrogate for steroids
Sucratose	150 µg/L	Range: <0.1 - 6.0 µg/L <sup>2</sup>	Range: <0.1 - 0.39 µg/L <sup>3</sup>	Surrogate for water soluble, uncharged chemicals, moderate MW
Triclosan	2100 µg/L	<0.010 µg/L <sup>2</sup>	<0.010 µg/L <sup>3</sup>	Chemical of interest

<sup>1</sup> In most cases, criterion based on drinking water equivalent concentration for lowest therapeutic dose divided by 1,000 or 10,000 to provide a safety factor.

<sup>2</sup> Based on 12 samples in finished water

<sup>3</sup> Based on 9 samples in finished water



## Total Coliform and E. Coli 50% and 99% values for TC and EC

Sept 14 – Present

### TC

TC	n	50%	99%
S1	31	19400	101370
S2	31	17	240
S3	31	0	2
S4.1	30	0	6
S4.2	30	2	11
S5.1	30	2	12
S5.2	30	4	115
S5.3	30	0	29
S6	31	0	0
S7.1	28	22	2031
S7.2	31	0	476
S7	31	1	1141
S8	29	0	3
S10	30	0	1

### EC

EC	n	50%	99%
S1	31	1320	12999
S2	31	0	1
S3	31	0	0
S4.1	30	0	1
S4.2	30	0	0
S5.1	30	0	0
S5.2	30	0	0
S5.3	30	0	0
S6	31	0	0
S7.1	28	0	0
S7.2	31	0	0
S7	31	0	0
S8	29	0	0
S10	30	0	0

- Positive hits on filters
- DOW and TORAY swapped but still continued to get hits



# Total Coliform, E. Coli and Enterococcus S6 and S10.

Date	S6 (UVD)		S10 (UVAOP)	
	Total Coliform	E. Coli	Total Coliform	E. Coli
	MPN/100mL	MPN/100mL	MPN/100mL	MPN/100mL
7/20/2016	31	<1	No sample	No sample
7/27/2016	No sample	No sample	<1	<1
8/3/2016	5	5	<1	<1
8/10/2016	No sample	No sample	<1	<1
8/17/2016	1	<1	<1	<1
8/19/2016	<1	No sample	<1	<1
8/22/2016	<1	No sample	<1	<1
8/24/2016	<1	<1	<1	<1
8/26/2016	<1	<1	<1	<1
8/29/2016	<1	<1	<1	<1
8/31/2016	<1	<1	No sample	No sample
9/2/2016	1	<1	1	<1
9/9/2016	<1	<1	<1	<1
9/12/2016	770	4	15	<1
9/14/2016	<1	<1	<1	<1
9/16/2016	<1	<1	<1	<1
9/19/2016	<1	<1	<1	<1
9/21/2016	<1	<1	<1	<1
9/23/2016	<1	<1	<1	<1
9/26/2016	<1	<1	No sample	No sample
9/28/2016	<1	<1	<1	<1
9/30/2016	<1	<1	<1	<1
10/3/2016	<1	<1	<1	<1
10/5/2016	<1	<1	<1	<1
10/7/2016	<1	<1	<1	<1
10/12/2016	<1	<1	<1	<1
10/14/2016	<1	<1	<1	<1
10/17/2016	<1	<1	<1	<1
10/19/2016	<1	<1	<1	<1
10/21/2016	<1	<1	<1	<1

Date	S6 (UVD)		S10 (UVAOP)	
	Total Coliform	E. Coli	Total Coliform	E. Coli
	MPN/100mL	MPN/100mL	MPN/100mL	MPN/100mL
10/24/2016	<1	<1	1	<1
10/26/2016	<1	<1	<1	<1
10/28/2016	No sample	No sample	<1	<1
10/31/2016	<1	<1	<1	<1
11/2/2016	<1	<1	<1	<1
11/4/2016	<1	<1	<1	<1
11/7/2016	<1	<1	<1	<1
11/9/2016	<1	<1	<1	<1
11/14/2016	<1	<1	<1	<1
11/16/2016	<1	<1	<1	<1
11/18/2016	<1	<1	<1	No sample
11/21/2016	<1	<1	<1	<1
11/28/2016	<1	<1	<1	<1
11/30/2016	<1	<1	<1	<1
12/2/2016	<1	<1	<1	<1
12/5/2016	<1	<1	1	<1
12/7/2016	<1	<1	<1	<1
12/9/2016	<1	<1	<1	<1
12/12/2016	<1	<1	<1	<1
12/14/2016	<1	<1	<1	<1
1/4/2017	<1	<1		
1/6/2017	<1	<1		
1/9/2017	<1	<1		
1/11/2017	<1	<1		
1/13/2017	<1	<1		
1/18/2017	<1	<1		
1/20/2017	<1	<1		
1/23/2017	<1	<1		
1/25/2017	<1	<1		
1/27/2017	<1	<1		

Date	Enterococcus (MPN/100mL)		
	S1 (Pilot Feed)	S6 (UVD)	S10 (UVAOP)
12/5/2016	200	<1	<1
12/12/2016	200	<1	<1
1/9/2017	200	<1	
1/23/2017	510	<1	

## Contaminants of Emerging Concern (CECs)

- Pilot has demonstrated good reduction and removal of CECs in both GAC and RO based trains
- Total number of measured CECs, per sample date:

Date	Pilot Feed*	GAC1 Eff	GAC2 Eff	UVAOP Eff
6/22/2016	23	N/A	N/A	1
8/17/2016	24	0	0	1
8/31/2016	24	4	1	2
9/28/2016	27	4	1	2
10/12/2016	30	4	1	1
10/26/2016	20	3	2	2
11/9/2016	22	5	6	3
12/7/2016	33	6	2	1
Total	203	26	13	13

\*A total of 96 CECs are measured at each location on each sample date



## Contaminants of Emerging Concern (CECs)

- Treatment case study for 8/31/16
- Multi-barrier approach is shown by decrease in concentration through the treatment process
- All values shown in ng/L

Contaminant	Pilot Feed	Ozone Eff	BAC1 Eff	BAC2 Eff	GAC1 Eff	GAC2 Eff	RO Eff	UVAOP Eff
Iohexal	7500	4000	1500	1400	15	<10	31	<10
Sucralose	43000	28000	17000	12000	<100	<100	140	130
TCPP	980	720	260	110	<100	<100	<100	<100
Primidone	130	46	28	21	<5	<5	<5	<5



## Contaminants of Emerging Concern (CECs)

Contaminant	Pilot Feed	GAC1 Eff	GAC2 Eff	UVAOP Eff
Sucralose	260000	61000	<100	<100
Sulfamethoxazole	4100	<5	7.9	<5
4-nonylphenol	2200	870	690	800
Acesulfame-K	2100	870	130	<20
Lidocaine	1800	<5	<5	<5
Theobromine	520	<10	<10	<10
Cimetidine	450	<5	<5	<5
TCPP	330	<100	<100	<100
TDCPP	220	<100	<100	<100
Dilantin	190	<20	<20	<20
4-tert-octylphenol	160	170	190	340
TCEP	130	<10	<10	<10
BPA	93	<10	52	<10
Atenolol	87	<5	<5	<5
Albuterol	41	<5	<5	<5
DEET	30	<10	<10	<10
Carisoprodol	18	<5	<5	<5
Testosterone	13	<5	<5	<5
Diuron	12	<5	<5	<5
DEA	11	<5	<5	<5
Androstanedione	9.5	<5	<5	<5
Dehydronifedipine	5.9	<5	<5	<5

- Treatment case study for 11/9/16
- All CECs measured in pilot feed are shown
- All values in ng/L



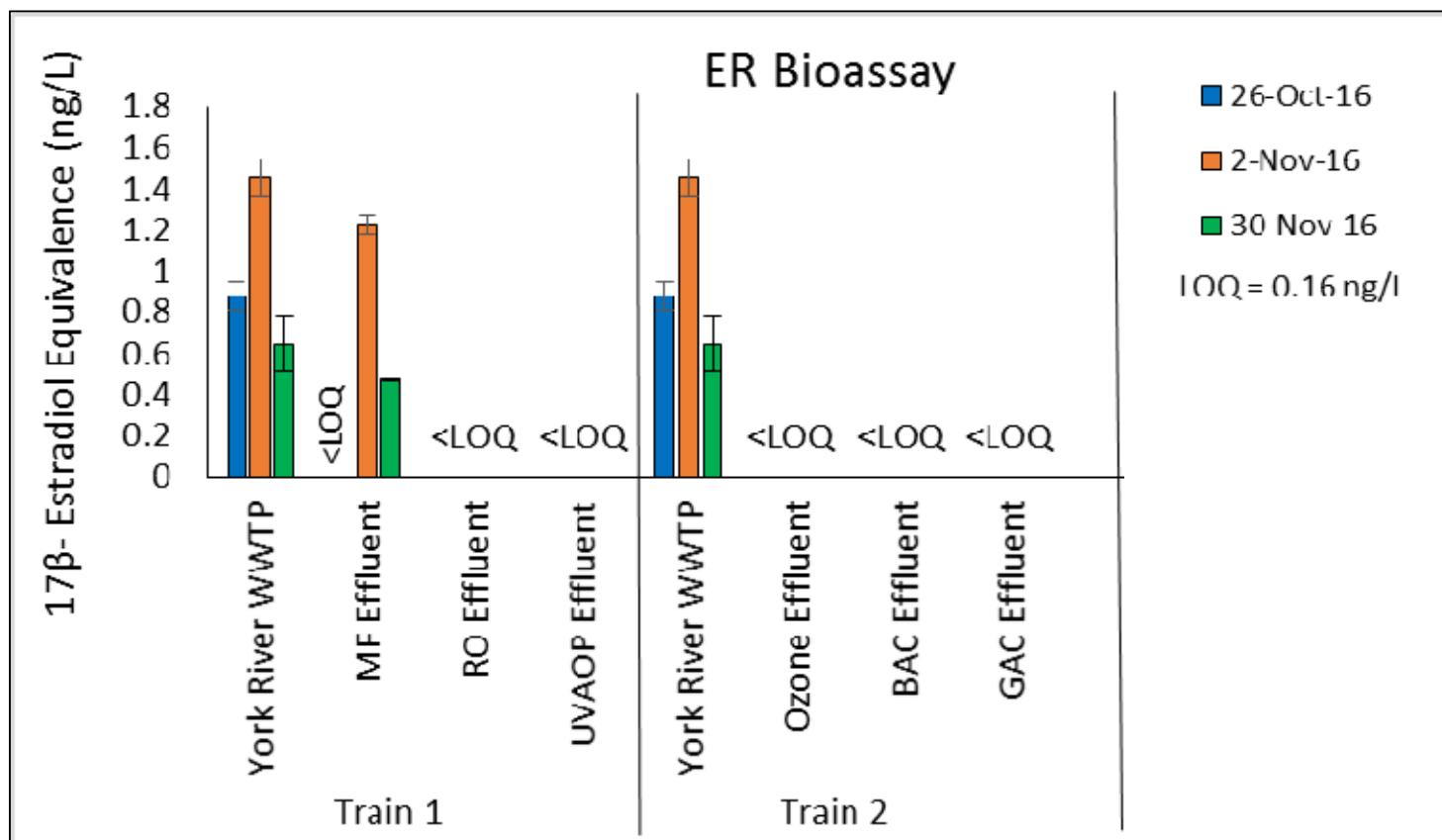
## Frequently Measured CECs

Contaminant	Total Recorded*	Type
Sucralose	26	Sugar Subsitute
Acesulfame-K	24	Sugar Subsitute
Iohexal	24	Contrast Agent
4-nonylphenol	20	Manufacturing Compound
TCEP	14	Flame Retardant
TCPP	12	Flame Retardant
TDCPP	12	Flame Retardant
DEET	11	Insect Repellent
Primidone	11	Prescription Drug
Lidocaine	10	Prescription Drug
Atenolol	9	Prescription Drug
Cotinine	9	Metabolite of Nicotine
Carbamazepine	8	Prescription Drug
4-tert-octylphenol	7	Manufacturing Compound
Triclosan	7	Preservative

\*A total of 43 samples were taken through the pilot treatment trains from Jun 22 to Dec 7, 2016

## Preliminary Bioassay Results

- Estrogen Receptor Bioassay:
  - Response is fully attenuated after RO treatment
  - Response is fully attenuated after Ozone treatment



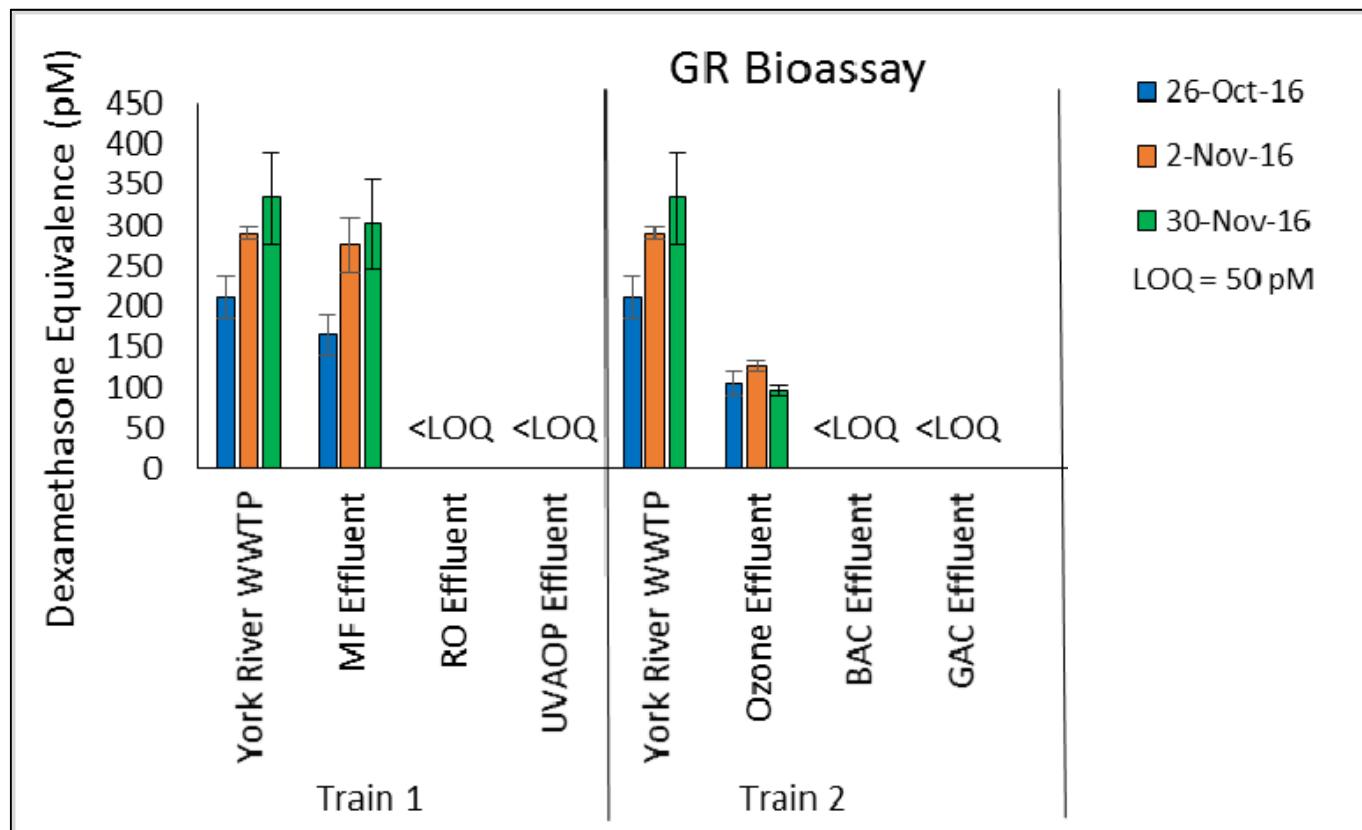
WE&RF Project Reuse-15-04

Sustainable Water Initiative for Tomorrow

## Preliminary Bioassay Results

- Glucocorticoid Receptor Bioassay:

- Response is fully attenuated after RO treatment
- Response decreases with ozone treatment and is fully attenuated after BAC treatment



WE&RF Project Reuse-15-04

Sustainable Water Initiative for Tomorrow



## Preliminary Bioassay Results

- Cytotoxicity (HepG2):

- All samples from the first 3 sampling campaigns did not show cytotoxicity at a final concentration of 12.5x the original sample

- p53 Bioassay:

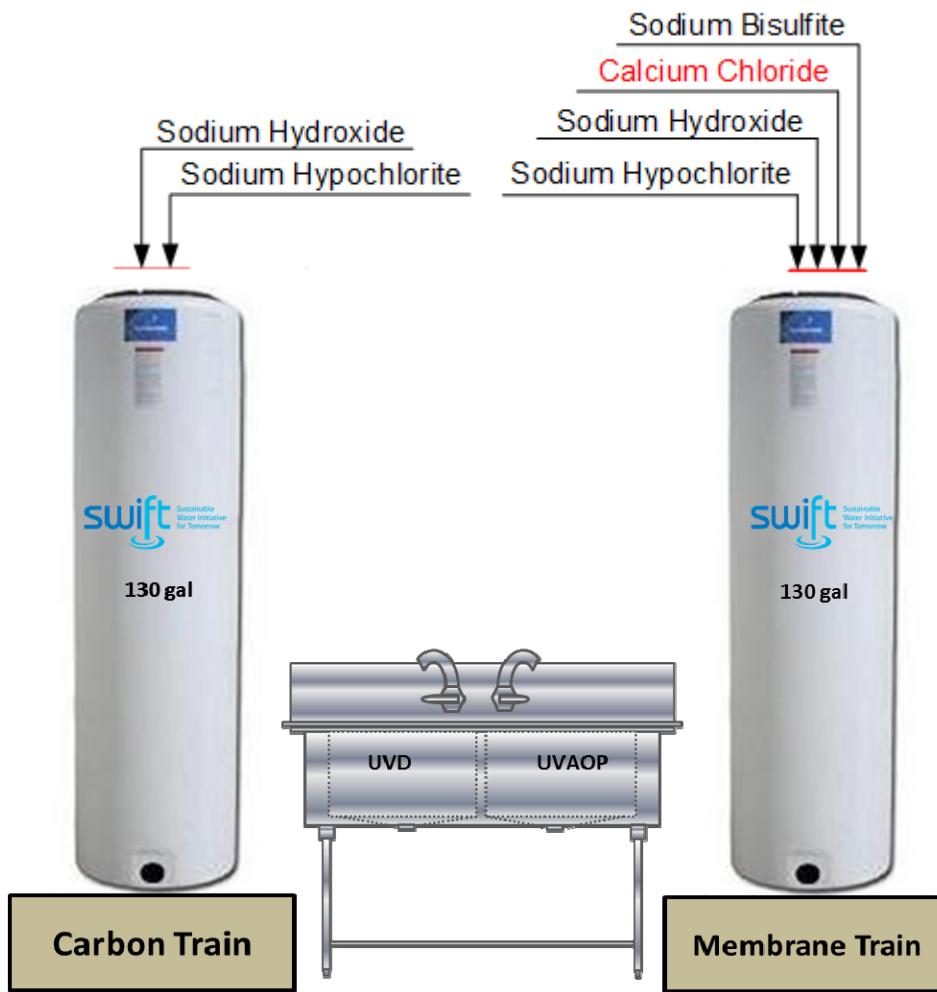
- All samples from the first 3 sampling campaigns did not show any interaction within this pathway (were <LOQ)



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## SWIFT Event



- 24 hours turbidity check before filling the finished water tanks.
- All chemicals used were NSF certified.



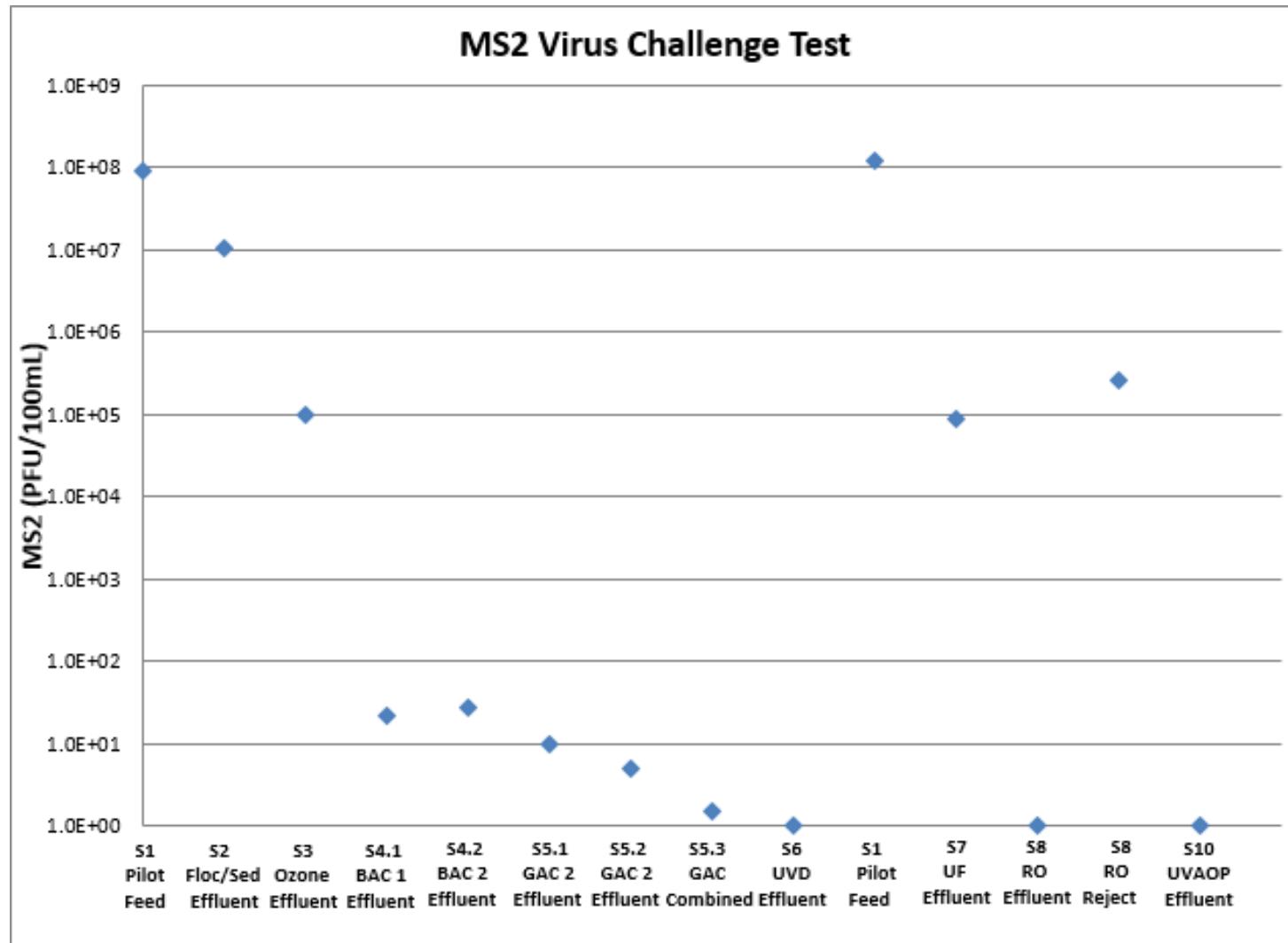
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## Virus Challenge Testing

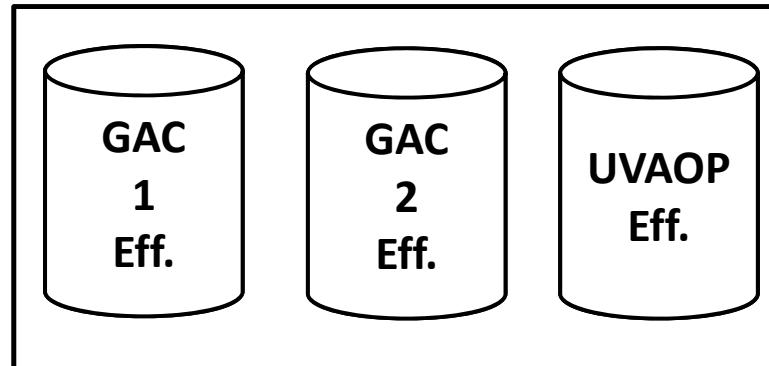
- Purchased MS2 Stock Solution of >10<sup>12</sup> PFU/100mL
- Diluted to 10<sup>8</sup> PFU/100mL at pilot feed
- Both trains achieved >8 LRV for MS2 virus with non-detect values prior to final treatment steps
- Considering performing additional testing

Location	LRV
GAC TRAIN	
Floc/Sed	1
Ozone	2
BAC	3.5
GAC	>1
CI2	N/A
UVD	N/A
RO TRAIN	
UF	3
RO	>5
UVAOP	N/A

## Virus Challenge Testing



## Disinfection Byproduct Testing



- Conditions:

- pH: 7.5-7.7
  - Free chlorine residual of 0.5 mg/L after 8 hours
  - Not exposed to light.
  - Samples at:
    - Initial (no Cl<sub>2</sub>)
    - 30 min
    - 2 hours
    - 8 hours
    - 3 days
- Analysis:
- UVT
  - DOC
  - TTHM
  - HAA9
  - Total Organic Halide
  - Nitrosamines
  - Free chlorine



## DBP Testing - Free Chlorine Results

	GAC 1 (S_5.1)					GAC 2 (S_5.2)					UVAOP (S_10)				
	Initial	30 min	2 hours	8 hours	3 days	Initial	30 min	2 hours	8 hours	3 days	Initial	30 min	2 hours	8 hours	3 days
Free Chlorine residual (mg/L)	0.1	*1.3	1.0	0.3	0.1	0.1	*1.6	1.1	0.8	0.1	0.0	*0.8	0.9	0.8	0.9
DOC (mg/L)	3.7	3.7	3.6	3.6	3.7	2.5	2.4	2.5	2.5	2.6	0.2	0.2	0.2	0.2	0.2
UVT (%)	86.3	86.8	86.8	86.9	87.4	89.3	89.5	89.5	89.6	90.1	94.4	93.4	93.5	92.8	93.9
Trihalomethanes (ug/L)															
Bromodichloromethane	ND	2.1	3.8	6.7	7.7	ND	ND	ND	3.4	5.1	ND	ND	ND	ND	ND
Bromoform	ND	7.8	15.1	30.5	47.2	ND	5.4	10.5	19.6	60.8	ND	ND	ND	ND	ND
Dibromochloromethane	ND	6.2	11.9	21.8	31.0	ND	4.0	7.6	13.4	27.5	ND	ND	ND	ND	ND
Chloroform	ND	ND	ND	ND	2.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
<b>TTHM's (MCL: 80 ug/L)</b>	ND	16.2	30.8	59.0	88.0	ND	9.4	18.1	36.4	93.3	ND	ND	ND	ND	ND
Nitrosamines (ng/L)															
N-Nitrosodibutylamine (NDBA)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
N-Nitrosodiethylamine (NDEA)	ND	ND	ND	ND	2.3	4.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
N-Nitroso-dimethylamine (NDMA)	13.0	12.0	13.0	14.0	16.0	2.6	2.6	2.7	2.9	2.8	ND	ND	ND	ND	ND
N-Nitrosodi-n-propylamine (NDPA)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
N-Nitrosodiphenylamine (NSPhA)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
N-Nitrosomethylalkylamine (NMEA)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
N-Nitrosomorpholine	3.8	4.4	3.6	3.7	3.3	3.9	3.8	3.4	3.6	2.9	ND	ND	ND	ND	ND
N-Nitrosopiperidine (NPIP)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
N-Nitrosopyridine (NPYR)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Haloacetics Acids 9 (ug/L)															
Bromochloroacetic acid	ND	1.9	2.3	2.8	5.3	**	**	**	**	4.3	ND	ND	ND	ND	ND
Bromodichloroacetic acid	ND	6.6	11.0	15.0	ND	**	**	**	**	ND	ND	ND	ND	ND	ND
Chlorodibromoacetic acid	ND	ND	ND	2.6	2.7	**	**	**	**	2.3	ND	ND	ND	ND	ND
Dibromoacetic acid	ND	8.5	10.0	12.0	14.0	**	**	**	**	15.0	ND	ND	ND	ND	ND
Dichloroacetic acid	ND	1.6	1.8	1.9	2.2	**	**	**	**	ND	ND	ND	ND	ND	ND
Monobromoacetic acid	ND	ND	1.5	2.3	1.4	**	**	**	**	1.6	ND	ND	ND	ND	ND
Monochloroacetic acid	ND	ND	ND	ND	ND	**	**	**	**	ND	ND	ND	ND	ND	ND
Tribromoacetic acid	ND	ND	4.7	5.4	ND	**	**	**	**	ND	ND	ND	ND	ND	ND
Trichloroacetic acid	1.1	1.2	1.3	1.3	ND	**	**	**	**	ND	ND	ND	ND	ND	ND
<b>HAA5 (MCL: 60 ug/L)</b>	1.1	11.3	14.6	17.5	17.6	**	**	**	**	16.6	ND	ND	ND	ND	ND
Total Organic Halides (ug/L)	42.0	170.0	160.0	260.0	180.0	30.0	180.0	240.0	220.0	140.0	ND	ND	ND	ND	12.0

\*Initial dose for both GACs were 3 mg/L and for UVAOP was 6 mg/L

\*\*HAA9 analysis was cancelled due to residual chlorine in samples

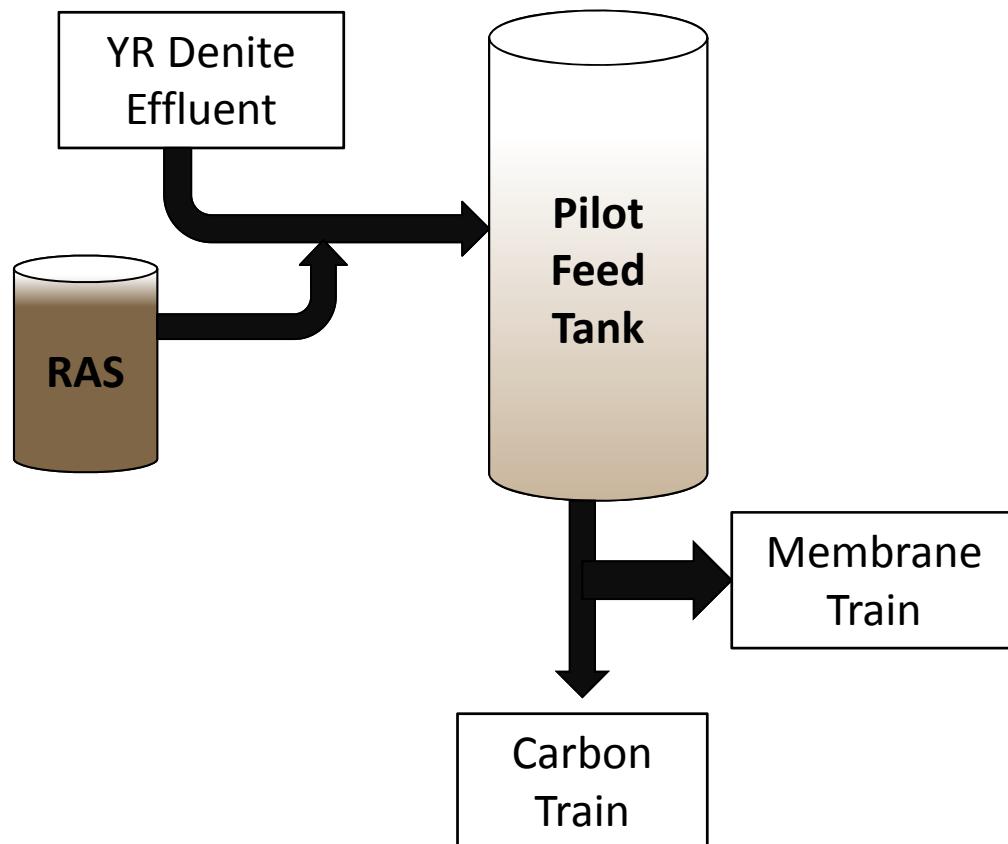


## DBP Testing – Monochloramines Results

	GAC 1 (S_5.1)					GAC 2 (S_5.2)				
	Initial	30 min	2 hours	8 hours	3 days	Initial	30 min	2 hours	8 hours	3 days
Free Chlorine/Monochloramine residual (mg/L)	NA	0.95	0.89	0.78	0.3	NA	0.98	0.98	0.84	0.54
TOC (mg/L)	4.08	4.02	4.09	4.25	4.08	3.32	3.27	3.32	3.27	3.22
UVT (%)	89.96	89.17	88.92	89.80	89.94	92.41	91.69	91.61	92.02	92.27
Bromide				0.515					0.516	
Trihalomethanes (ug/L)										
Bromodichloromethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bromoform	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibromochloromethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chloroform	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TTHM's (MCL: 80 ug/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitrosamines (ng/L)										
N-Nitrosodibutylamine (NDBA)	ND	2.0	ND	ND	ND	ND	2.4	ND	ND	ND
N-Nitrosodiethylamine (NDEA)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
N-Nitroso-dimethylamine (NDMA)	3.4	4.4	2.7	3.2	6.4	ND	ND	ND	ND	2.6
N-Nitrosodi-n-propylamine (NDPA)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
N-Nitrosodiphenylamine (NSPhA)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
N-Nitrosomethylalkylamine (NMEA)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
N-Nitrosomorpholine	3.8	5.0	4.1	3.5	4.7	4.2	4.0	3.4	4.4	4.9
N-Nitrosopiperidine (NPIP)	ND	2.5	ND	ND	ND	3.0	2.5	ND	3.4	4.0
N-Nitrosopyrrolidine (NPYR)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Haloacetics Acids 9 (ug/L)										
Bromochloroacetic acid	ND	ND	ND	ND	1.1	ND	ND	ND	ND	1.3
Bromodichloroacetic acid	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chlorodibromoacetic acid	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibromoacetic acid	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dichloroacetic acid	ND	1.6	1.7	1.9	2.8	ND	ND	1.0	1.2	1.7
Monobromoacetic acid	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Monochloroacetic acid	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tribromoacetic acid	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Trichloroacetic acid	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HAA5 (MCL: 60 ug/L)	0.0	1.6	1.7	1.9	2.8	0.0	0.0	1.0	1.2	1.7
Total Organic Halides (ug/L)	40.0	200.0	180.0	160.0	130.0	30.0	220.0	200.0	210.0	150.0

\*Initial dose for both GACs were 1 mg/L

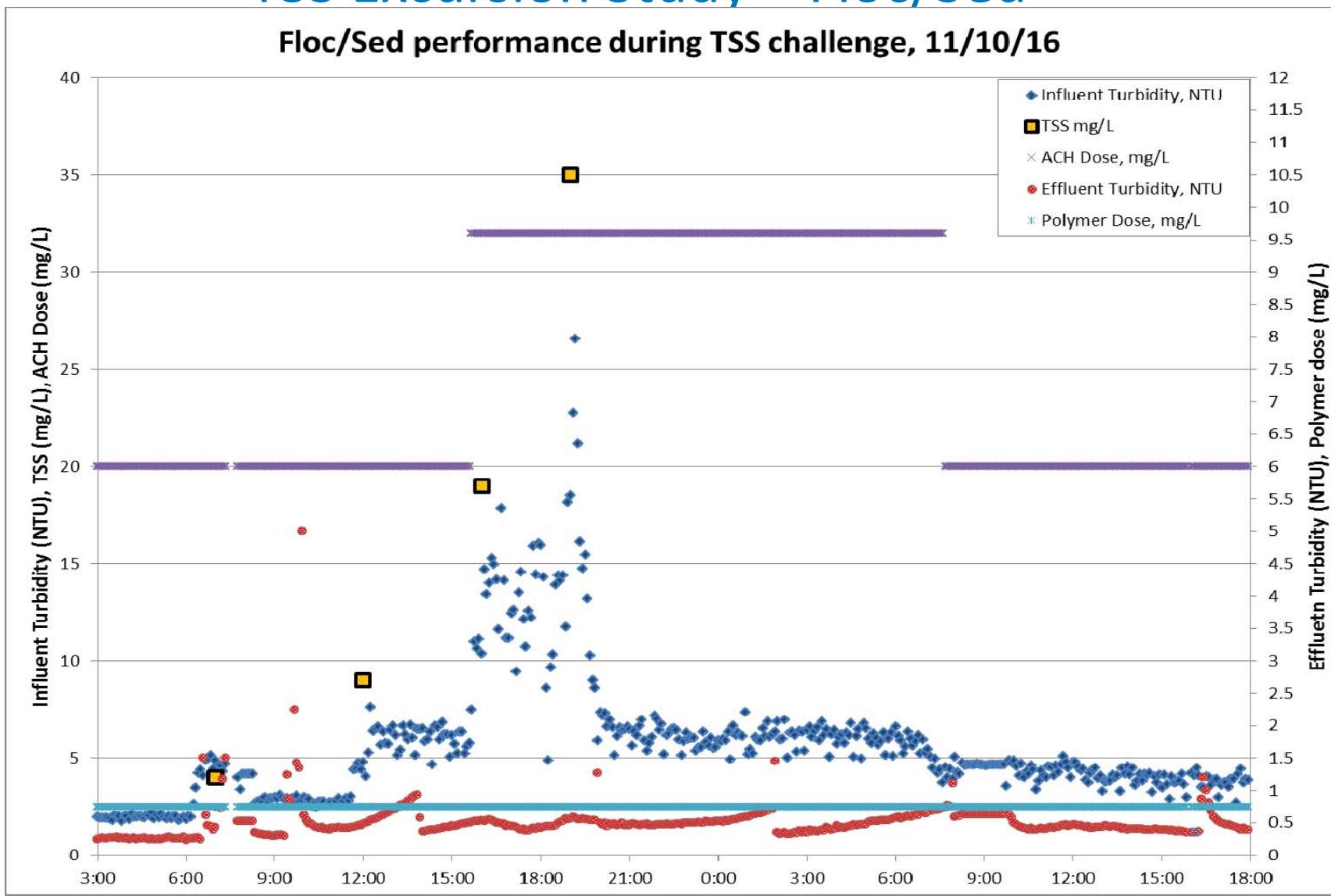
## TSS Excursion Study



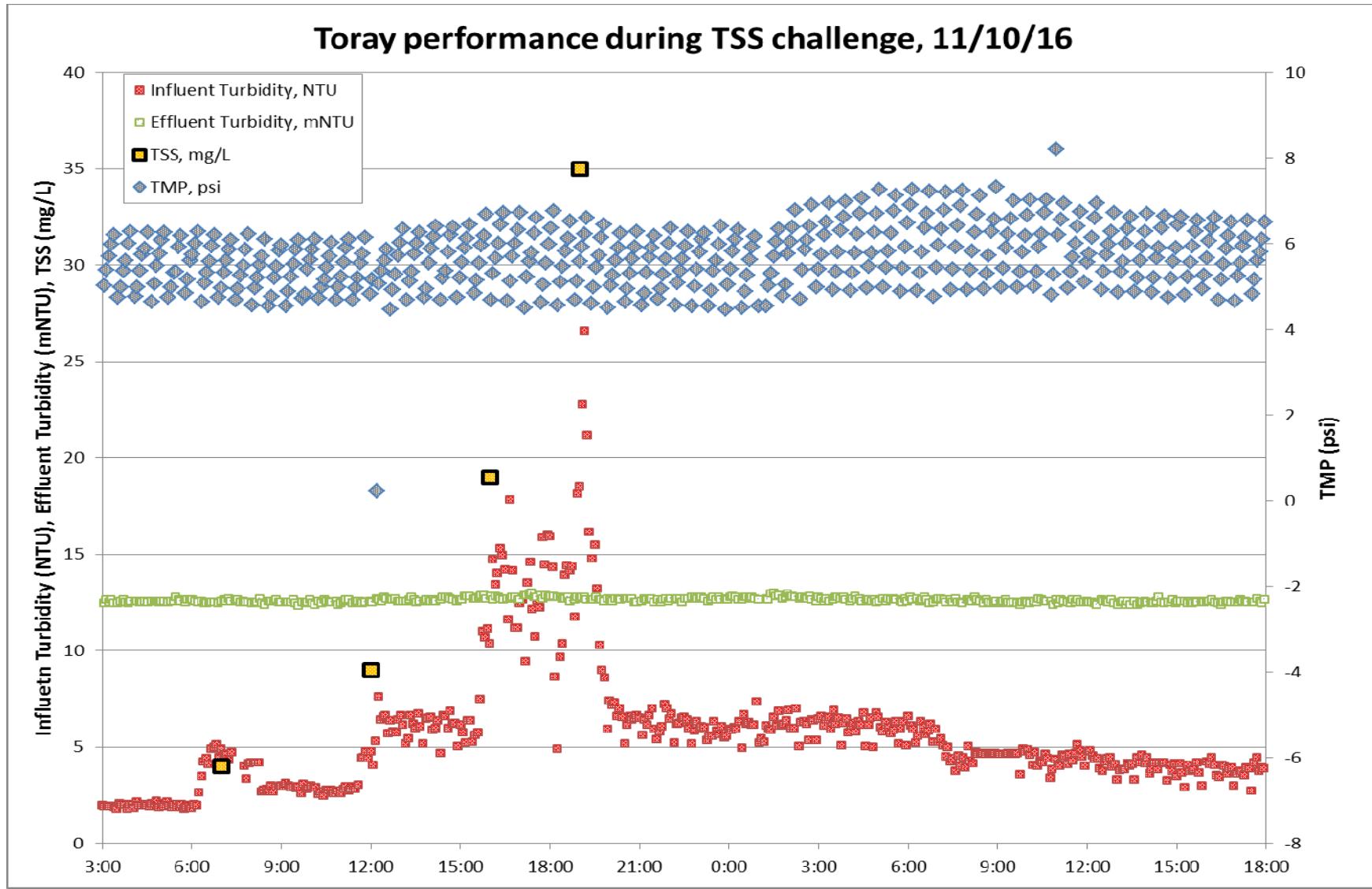
- Normal Operation:
  - Pilot feed tank TSS: 5 mg/L
  - F/S ACH dose: 20 mg/L
  - F/S Polymer dose: 0.75 mg/L
- Based on jar testing:
  - F/S ACH dose: 32 mg/L
  - F/S Polymer dose: 0.75 mg/L
- Actual test:
  - 5 to 10 mg/L TSS for 12 hours
  - 10 to 40 mg/L for 4 hours
  - 40 to 10 mg/L for 8 hours
  - Back from 10 to 5 mg/L.

## TSS Excursion Study – Floc/Sed

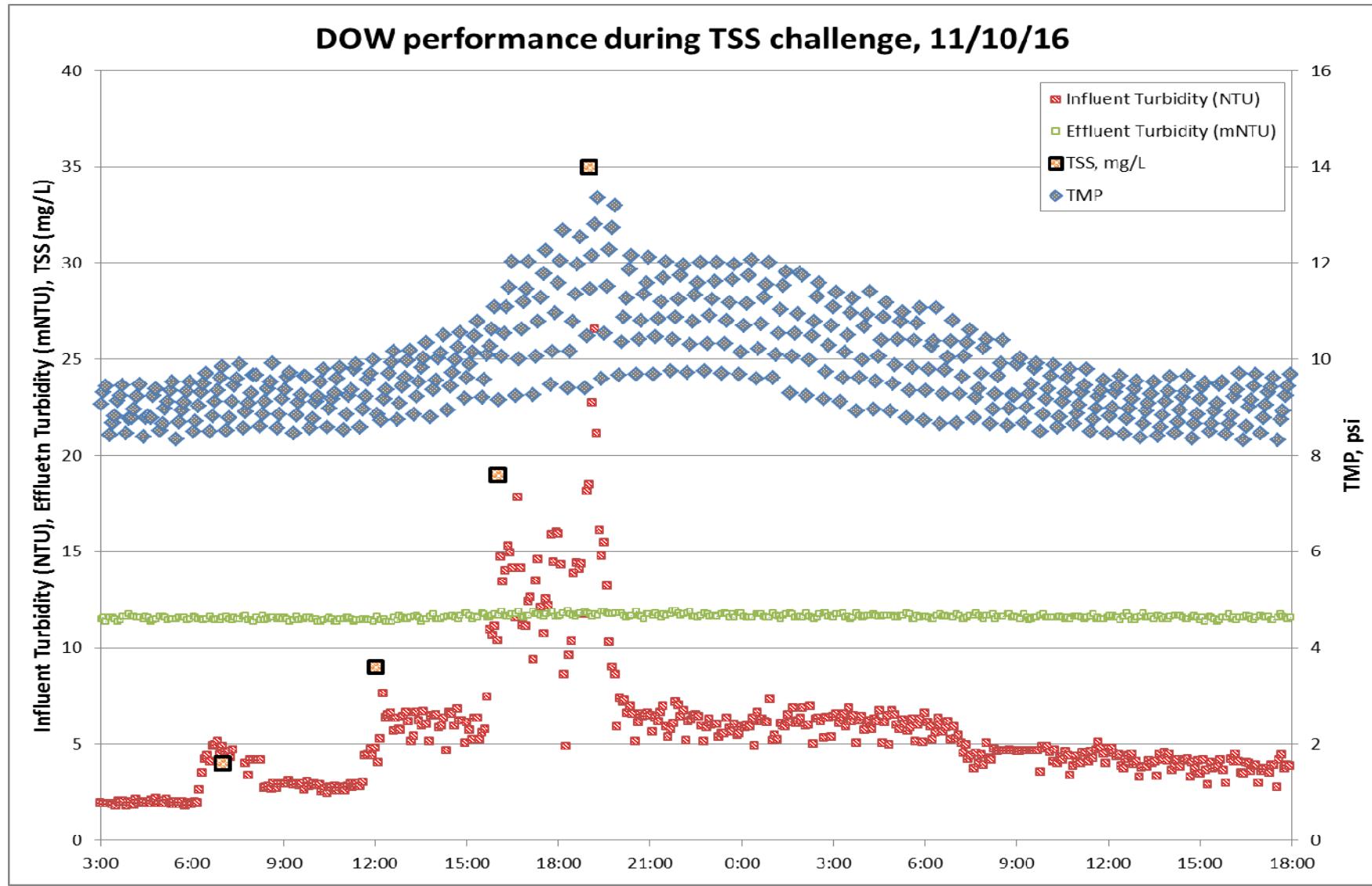
Floc/Sed performance during TSS challenge, 11/10/16



## TSS Excursion Study – UF Toray



## TSS Excursion Study – UF Dow

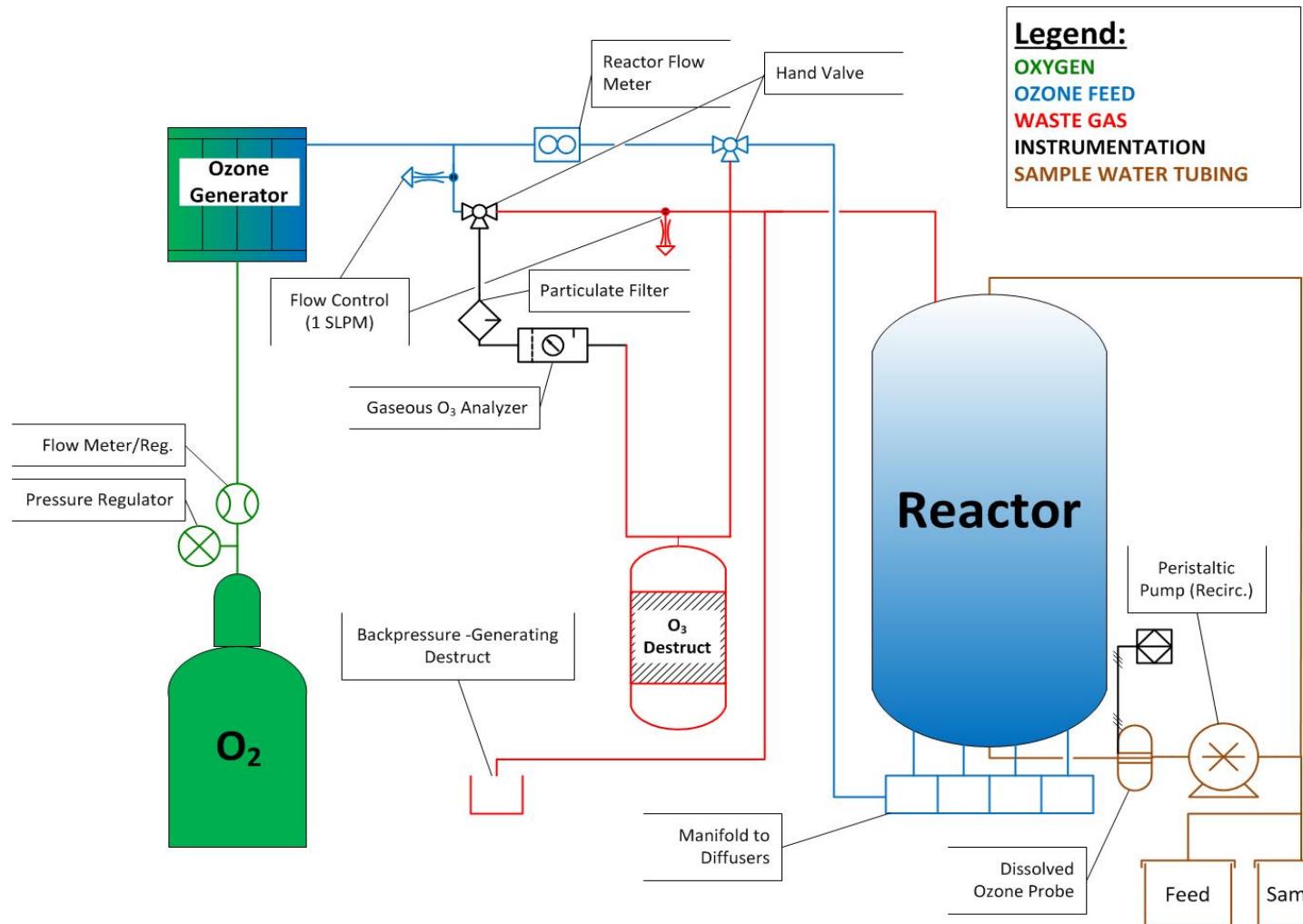


## *Pilot Next Steps*



Sustainable Water Initiative for Tomorrow

# Ozone Bench Testing



## Ozone Bench Testing Variables

- Used to optimize ozone process while simultaneously suppressing bromate
- Variables:
  - Applied ozone dose
  - Temperature
  - Influent Nitrite and Ammonia
  - Influent Bromide
  - Monochloramine addition
  - Ammonia addition
  - pH suppression
- Will also be used to support BDOC Testing
  - Evaluate BDOC in secondary effluent of 7 candidate SWIFT facilities
  - Evaluate BDOC through pilot process
  - Utilize BDOC to estimate TOC removal at NTP demonstration facility

## Rapid Small Scale Carbon Testing

- CH2M's Applied Science Lab (ASL) is currently performing RSSCT to:
  - Understand performance of BAC filters at end of carbon life
  - Compare two different carbon products
- Testing will be complete in early February
- 4 drums of BAC effluent (10 min EBCT) was shipped to ASL
- Daily testing for TOC in RSSCT effluent
- Initial characterization and regular testing for CECs, NDMA, PFOS/PFOA, and 1,4-Dioxane

## Enhanced Coagulation

- Initial jar testing showed increased TOC removal using Ferric Sulfate coagulant at a depressed pH
- Because of high pilot feed ALK at York River, ACH coagulant was selected for the pilot
- Pilot team will perform additional jar testing to identify performance of coagulants at a range of pH values
- A pilot campaign may be performed at a depressed pH for an extended period of time